REMARKS
ON SOME
PROPERTIES OF LIGHT

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PREFACE.

As an explanation would seem to be necessary for commencing the publication of this Essay with one of its Parts only, and that not the First, I beg to state, that distrust of my own powers to do justice to the subjects severally treated of in them naturally deters me from venturing upon the publication of the whole work at once; for however encouraging may be the criticism of partial friends, their verdict might be reversed, or at least much modified, by the sterner tribunal before which it would have to appear.

I have selected the Fifth Part, because it is a fair specimen of the design and general scope of the work; and by the reception which it may meet with, I shall be mainly guided in dealing with the remaining portions. As a lover of TRUTH I do not deprecate, but rather court, the commentaries, and, if need be, the censure of the critic; well knowing, that whatever be my individual loss or gain, the cause of TRUTH (which alone should be the object of every dabbler in science) will benefit by the free discussion of scientific subjects.

I now commit this Part of my Essay to the consideration of those who feel an interest in the subject on which it treats; and I earnestly solicit their unreserved communications, whether they be for approval or for blame.

I hope, in a future Part, to make honourable mention of the friends by whose advice and assistance I have benefited in the composition of this Essay, and in the publication of this portion of it. I cannot, however, dismiss the present one, without paying a tribute to the memory of my departed friend, Henry Lawson, Esq., F.R.S., who spent the latter part of his life, and finished his earthly course, in this city. He was ever ready to assist me with his counsel, and to forward my labours

by the loan of such scientific volumes as I required from his library. Kind to the poor, and friendly to his neighbours, he was anxious at all times to promote works of public utility, especially if connected with the favourite studies which he himself pursued with unabated zeal as long as health and strength were granted to him. And as he completed in this city his allotted time, so did he carry with him to the grave the affectionate regards and kindly regrets of those among whom the evening of his days was spent. It were to be wished that the last year of his life had not been saddened by the failure of his fondly-cherished plan of seeing his beloved instruments domiciled in a midland observatory. But this trial, destined as it was to be a portion of the discipline of his closing career, was acquiesced in with patience and resignation. In the memory of many pleasant hours passed in the society of my departed friend, I cast this slender garland upon his tomb:

> "His saltem accumulem donis, et fungar inani
> Munere."

KILKENNY HOUSE, SION HILL, BATH,
June 1856.

NOTICE.

THIS Essay, when complete, will contain Seven Parts, and the subjects to be treated in each Part are as follows:

I. On the causes of certain impediments to distinct Vision, as determined by experiment.

II. On the structure and external configuration of the cornea of the human Eye, and considerations on the use and abuse of small apertures, as aids to Vision.

III. On the practical education of the Eye; shewing experimentally the mode by which that organ is adjusted to the distinct view of objects situated at various distances from the observer.

IV. On the proper adaptation of optical instruments to the physical condition and structure of the Eye, and to the external circumstances by which it is affected.

V. Incidental remarks on some properties of Light.

VI. Conjectures, founded on the analogy of Light, as to the cosmical distribution of Matter; and

VII. Analysis of certain Papers communicated to the Royal Society, and published in their Transactions; and of certain Papers and Statements elsewhere published: thereby shewing how to guard against erroneous deductions and false judgments in Vision.

PART V.

INCIDENTAL REMARKS ON SOME PROPERTIES OF LIGHT.

In this division of the subject I propose to enter upon a practical investigation of certain properties of light, which, though not entirely unnoticed by writers on Optics, appear not to have been clearly understood, or even correctly stated.

The basis upon which I have grounded the argument is to be found in data distributed throughout the several parts of this Essay; and it is intended, in the present part, to bring the scattered elements into a narrow compass, so as to exhibit, as it were at one view, the co-ordinate principles of *lateral shadows* and *light of collateral irradiation.*

But in the treatment of a subject of this nature, our progress is impeded *in limine* by the principal difficulty; What do we know of LIGHT? What do we know even of solar light, save by the superficial glances we obtain of the chemical action which it is wont to exercise upon bodies, and by its mechanical effect upon the organs of sight? Some have made it a question whether the sun have any inherent light, and whether he be more than a passive agent for its diffusion by reflexion from an external cause. Hypotheses, indeed, respecting both his light and heat, have been many, some of which possess little merit beyond an ingenious plausibility; while others, more congruous, seem to have seduced their authors into the pleasant fields of Fancy, where, listening to the music of some purling stream, or pouring forth their voice in measured

strains to the tones of the melodious pipe, they sang of Nature and the things that be. And if, yielding to the same enchantment, and wandering amid the pastures of Arcadia, I, too, sound my feeble reed, may the allurements of those peaceful regions not lead my footsteps astray, or leave me friendless in the happy land!

Entering then upon the inquiry, namely, *what is* LIGHT? we can only reply to the question by saying; That its source is unknown, its supply inexhaustible: ever flowing and never exuberant;

> "Largus item liquidi fons luminis, æthereus sol
> Irrigat assidue cœlum candore recenti."[1]

That the luminous flood cannot be accelerated, and, when partially obstructed, that additional energy is thereby given to the stream. That in its effusion from the sun, it proceeds at the rate of 190,000 miles in a second of time, and with a momentum estimated by Mr. Michel[2] at the 1800 millionth part of a grain on a square foot of the earth's surface. Yet such is its astonishing tenuity, that the least substantial vapour breaks its rays into fragments, and scatters them, split and trembling, to the earth. That its waves, though dashing with impetuosity against the pupil of the eye, yet inflict upon the exquisitely organized retina only the most pleasurable sensations. That it plays on the wings of the ichneumon, and quickens the pulse of the ephemera. It illuminates the Milky Way, and marks the track of the comet. It flashes in the gem, sparkles in the wave, lives in the laughing eye, and expires in the fleeting dew-drop. It imparts beauty to the lily, pertness to the daisy, grace to the oxalis, and extracts perfume from the rose. The sun-loving pimpernel closes her bright eye in sadness at the departure of her lord, the lark ceasing her song, and the dove retiring to her cote. The shepherd counts the lingering hours by the circling light of the Wain; the sailor steers for the hoped-for haven by the flickering beams of the pole-star; and the incautious traveller rushes on his doom by following the treacherous blaze of the ignis fatuus.

[1] Lucret. lib. v. ver. 281. [2] Walker's Lectures, Art. Optics, p. 72.

Lo, it warms in the lamp of the glow-worm, and burns in the torch of the fire-fly. It ripens the golden harvest, mellows the juice of the vine, and gives potency to the pain-soothing poppy. It thrills in the nerves of the gymnotus and torpedo, is resplendent in the aurora, majestic in the meteor, fearful in the lightning's dart, and terrible in the throes of the volcano.

If, then, so much, and all too little, can be said of the light, which, obeying the fiat of THE OMNIPOTENT[1], sprang suddenly into existence, and filling sidereal space with its effulgence, instantly lighted up the orbs of heaven, how shall we be able even remotely to appreciate the attributes and perfections of HIM who created that light, who in the beginning made the heavens and the earth, and whose Spirit moved upon the face of the waters[2]; who spake in the burning bush[3]; and who, by the pillar of a cloud, and by the pillar of fire led, HIS people through the waters and preserved them in the wilderness[4]; whom "the heaven of heavens cannot contain"[5]; whose coming in the flesh was denoted by the leading of a star[6]; and who HIMSELF was that Light which "shineth in darkness, and the darkness comprehended it not."[7] Since, therefore, "such knowledge is too wonderful for us," we will henceforth confine our efforts to an examination of that material light which comes more immediately within the province of this Essay.

EXP. 21. Having placed a certain number of candles in a row, I held a card finely perforated immediately parallel to the line of lights, so that, were it possible, rays from each flame might pass freely through the aperture, and, emerging therefrom, fall directly on a screen held at a short distance behind the card. On looking at the screen, I observed as many spots of light upon it as corresponded to the number of candles. And by doubling the number of the latter, without extending the line, no other effect was observed to take place beyond an

[1] Genesis i. 3. [2] Idem. i. 2. [3] Deut. xxxiii. 16.
[4] Exod. xiii. 21. [5] 2 Chron. ii. 6. [6] Matth. ii. 9.
[7] Gospel of St. John i. 5.

additional number of luminous spots on the screen. These spots, however, fell nearer to each other; but being projected on the same dark background, and in a line, each spot was perfectly distinct, and all were equally well defined. It would seem, therefore, that the element of light must be essentially different from every other with which we are acquainted, since the luminous matter emitted from so many flames produced no confusion, or interference with each other by mutual obstruction in passing through so small an aperture. And as these unobstructed rays proceeded through the aperture in straight lines, and projected shadows from the edge of the aperture also in straight lines, no appearance of "inflexion of light" was developed by the phenomenon. It may therefore be legitimately inferred, that had there been a sufficient number of candles to cause the flames to join, and by their juncture to form one continuous line of light, the light thus emitted by so many additional radiants distributed over the longitudinal flame would have exhibited on the screen a corresponding luminous line. But the same, or intermediate radiants, would likewise project a corresponding number of shadows from the edge of the aperture of the card, which, crossing the direct rays after emerging from the pin-hole, would fall alternately, at equal intervals with the latter, on the screen. Hence, instead of a continuous line of light appearing on the latter, there would be a succession of spots of bright and shaded light; the former being, as it were, impoverished by shadow, and the latter illuminated by direct light after its exit from the pin-hole, and before it fell on the screen. This will be better understood by referring to the following diagram.

Exp. 22. Having divided a card into two equal parts, replaced their edges; and on looking through the crevice at the flame of a candle, I beheld immediately behind the former, and parallel to it, a succession of alternate *bright and dark lines* of uniform width. The former were somewhat fainter than direct light

from the candle, and the latter somewhat lighter than shadow from the card.[1]

Dr. Jurin attempts to explain this phenomenon partly by Newton's theory of "*fits of easy refraction and easy reflexion,*" and partly by the doctor's own hypothesis of "*a circle of dissipation.*[2] But it appears to me that his own hypothesis is grounded upon a fallacy in vision.

To ascertain, however, whether, and to what extent, fits of easy reflexion and easy refraction might apply to the case under consideration, I placed a lighted candle close to one of the edges of a plane mirror about three feet in width, and advancing my eye at the same distance to its other edge, I could perceive, on looking into the mirror, not fewer than twelve angular reflexions of the flame, besides the primary image, known by its superior brightness, and by its standing at the head of the others. Each flame was separated from that next to it by a considerable space, as in Exp. 21. They stood in a line perpendicular to the plane of the mirror, and being projected in perspective, each flame diminished in size and in brightness down to the last, which latter was scarcely discernible.

I then retired backwards a pace; by which movement the flames, appearing also to retire in line, kept the primary as the centre of motion. Another step backwards brought all the flames into a line with the eye; and they being huddled together in a state of great apparent disorder, and the edges of some overlapping the edges of others, while the sections not thus in duplicate were thin, flat, and misty, and admitting a view through them of all the interior images, the effect was similar in all essential respects to the phenomenon of the bright and dark lines of Dr. Jurin's experiment.

[1] At the time of my making the above experiment, I was not aware that it had been done by Dr. Jurin, who used a pair of parallel rulers for the purpose. But having become subsequently acquainted with the fact, I hereby acknowledge his claim to priority, in regard to the experiment itself; but I am in no way indebted to him for its explanation.

[2] See his "Essay on Distinct and Indistinct Vission," p. 157.

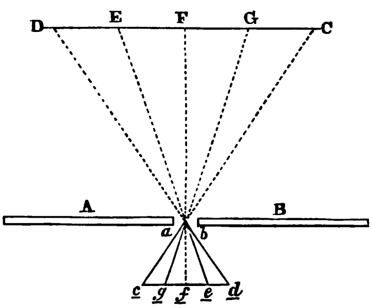
I now removed the candle to the centre of the mirror, and standing on the right of the former, I could see but one primary and two secondary flames reflected, namely, one on the left and two on the right of the primary. On moving towards the left of the candle, the secondary images appeared to move like satellites around their primary, in concentric circles. But when I reached the immediate front of the candle, the satellites became eclipsed by their primary. Passing on to the left, the orbits again opened, and the secondary images going round the primary in concentric circles as before, completed their revolutions by a retrograde movement. When, however, I reached a point on the left corresponding to another point on the right, at which the eclipse of the flames took place, the event was repeated, and attended with the same phenomenon of bright and dark lines, as when the twelve flames were amassed together. But in the former, as in the latter case, each flame occupied a separate plane, although the distances of the latter apart must have been extremely minute.

This experiment shews that the flame was twelve times reflected and twelve times refracted within the space comprised between the point of impact or incidence, and that at which the final ray emerged from the mirror; the primary being itself only once reflected from the *external* surface of the glass: but had the luminous matter not been exhausted, the number of angular reflexions and refractions would have been multiplied. There would appear, therefore, to be a strong resistance in glass to the free passage within its body of rays of light; so that after a certain number of consecutive angular reflexions, as between the anterior and posterior surfaces of a mirror, the luminous matter becomes gradually weaker and weaker after each reflexion, and is eventually exhausted and absorbed by the glass, as a river is lost in the ocean. And this, in the case of light, takes place the more rapidly, as an additional portion of the matter was refracted and passed out of the mirror from as many points as there were angular reflexions. Therefore the principle of fits of easy reflexion

and easy refraction, and that of a circle of dissipation, appear to have no application to the present case.

If, then, Dr. Jurin's elaborate explanations should be deemed unsatisfactory, and another be required, I venture to offer the following, founded on the principles stated at the commencement of this part of the Essay.

Let A and B be the two pieces of cut card joined at their edges *a* and *b;* and let D C be the horizontal diameter of the



flame. Then, if *c d* represent the diameter of the pupil of the eye, the shadow of the edge *a*, from the radiant D, will be projected on the pupil at *d;* and the shadow of the edge *b*, from the radiant C, will also be projected concurrently with the former on the pupil at *c*. Other shadows from the radiants E and G will likewise be projected on the pupil at *e* and at *g* respectively. But the radiant F having passed through the crevice, will, after crossing the lateral shadows *a e* and *b g* (by which the latter become faintly illuminated), proceed directly to the pupil at *f*; having itself become tainted, as it were, by those two lateral shadows. But other radiants between D E, E F, F G, and G C, would cause other shadows from *a* and from *b* to be projected on the pupil at corresponding points between *d e*, *e f*, *f g*, and *g c*. And as other intermediate rays would pass directly through the crevice *a b*, and fall at intermediate points directly on the pupil, the general effect upon the latter would be a succession of bright and dark lines, each parallel to the slit, as represented in the former diagram; but without the slightest indication of inflexion or diffraction of the rays of light: the latter having proceeded through the division *a* and *b* in straight lines, as well also as the intermediate lines of shadow from the edges *a* and *b*.

Sir Isaac Newton traces a strong analogy between refraction and reflection, in which, he says, some portion of incident light is always reflected, and some part refracted, at all transparent

surfaces.[1] This proposition, however, seems to require further elucidation. In Exp. 23, the only direct light refracted was that deflected at the external surface of the mirror. This might arise from an excess of luminous matter at the point of impact, and from the resistance offered by the glass to the reception into its substance of a fluid projected on its surface at the rate of 195,000 miles in a second of time. The retardation of the fluid thus caused might force the luminous particles in excess to fly off at the *angle-proper* of reflexion into the direction of the eye. I do not see how, therefore, according to this view, *fits of easy refraction and easy reflexion* apply to the present case; for when the light had entered the body of the glass, the stream of luminous matter being reflected and re-reflected within its substance from interior surface to interior surface, and being also simultaneously refracted at those several points towards the eye by a succession of impulses, these repetitions so diminished its volume, that it became finally exhausted by the operations, and melted, as it were, into the body of the glass.

Exp. 24. In order to compare the results of the above experiment upon glass, with a similar one upon the eye, I held a cedar pencil perpendicularly before the latter, so as to exclude from view the flame of a candle placed at a convenient distance for the purpose. I now saw several well-defined but semi-transparent lines on each side of the pencil, parallel to its edges, and having clear luminous spaces between them. The former were not all of uniform width; neither were the luminous spaces equal; nor did the broad line on one side correspond in position with the broad line on the other side of the pencil. These semi-opaque lines, passing over the top of the pencil, formed symmetrical arches there, without breaking their continuity. Thus, the narrow lateral A, on the extreme left of the series, curving over the top of the pencil formed the broad lateral a on the other side;

[1] Optics, p. 253.

and the broad lateral B, in like manner, formed the narrow lateral *b*. And so on with regard to the laterals C and D. By this process, the several arches mutually crossed each other at six different points, without disturbance at their several decussations.

Now, it appeared by Exp. 23, that rays of light and lines of shadow mutually crossed each other behind the cut card, and fell on the pupil at opposite points to those from whence the radiant matter was emitted. Therefore, in the present instance, opposite but co-ordinate effects must have taken place with respect to lateral shadows from the sides of the pencil. Consequently the laterals A *a*, B *b*, C *c*, and D *d* must be considered as conjugate pairs or shadows respectively; and therefore the pencil is hereby represented by a succession of edges falling near to each other. That is, A B C and D, being the supplementary edges of the left side of the pencil, *a b c* and *d* will be the corresponding edges of the right side of the same instrument. In the same way, luminous matter emitted by intermediate radiants on the right side of the flame, after impact on the right side of the pencil, would be deflected thence at the angles of total reflexion (namely, 175° up to 180° from the incident ray), and thereby partially illuminate the lateral shadows or images through which it passed. The latter, by this partial illumination, losing the character of opacity, become semi-transparent.

But it has been stated that the laterals were not all of the same width, although almost equally transparent, there being one wide lateral on the left, and another on the right, of the pencil, both occupying non-corresponding positions. Now, on a closer examination of these broad laterals, it will be found that they each consist of numerous other laterals, so close together, and divided by so narrow a line of faint light, that their individuality can with difficulty be distinguished. And the observer will perceive, on minute inspection, that the laterals thus closely packed together arise from the same cause as that by which the before-mentioned single ones were produced. That is to say, the single lines owed their origin to

secondary images or contours of the anterior portions, while the double ones resulted from the former in combination with secondary images of the posterior portions of the pencil. I have been the more minute in this account, as the phenomena developed bear a close resemblance to those of the dark lines seen by Fraunhofer, in his experiment on the solar spectrum.[1] For there would not appear to be any very obvious reason for supposing that these dark lines have an immediate connection with the physical condition of the sun's body or surface, or anomalous state of the solar light. When the edges of the pencil were repeated on each side of the principal image by subordinate contours, the phenomenon was manifestly the result of *lateral shadows*, each separated from the other by the *light of collateral irradiation*; so that each pair of edges represented a distinct pencil. It cannot be doubted, therefore, that, under similar circumstances, the surfaces of all transparent media, whether glass or iceland spar, whether solid or fluid, and whatever be the forms of their surfaces or the number of their angles, will be all, in like manner, repeated by the conjoint operation of *lateral shadows* and *light of collateral irradiation.*[2]

It was remarked by Huygens, Malus, and Young, that

[1] Edinb. Encyc., Art. Optics, Prop. xvi. p. 548.

[2] While this MS. was preparing for press, I received " No. I. Vol. xvi. Monthly Notice, Royal Astronomical Society, November 9, 1855," in which I find, at page 6, a communication from the Astronomer Royal, containing " Remarks upon certain cases of Personal Equation " which appear hitherto to have escaped notice. And it seems that the Astronomer Royal induced Mr. Dunkin (one of four observers to whom the former alludes) to draw up an account in a tabular form, shewing a " Comparison of the Observations for correction of Runs of Microscopes of Transit Circle, arranged according to observers." The Astronomer Royal does not suggest any assignable cause for the discrepancies of observation; but thinks the phenomenon may be worthy of the attention of the Royal Astronomical Society.

In Part I. of this Essay, which in the early part of 1852 was submitted to the inspection of the Council of the Royal Astronomical Society by John Lee, Esq., LL.D., I shewed by experiment a cause of error in regard to angular measurements with any kind of instrument, which appears to have escaped the attention of other observers; namely, that, owing to the

polarization of light might take place by reflexion "at proper angles" from the surface of any transparent medium, such as glass, water, &c. But they do not appear to have been aware that the light thus *polarized*, as it is called, is the ordinary *light of collateral irradiation*, unchanged in its physical character, but anomalously developed. They indeed recognised an analogy between reflected and refracted light, but do not seem to have entertained a true conception of the nature of that analogy, or of the extent, as a governing principle, to which it might be legitimately applied. M. Biot observes: "All light which has experienced the action of bodies by reflexion or refraction contains polarized rays, whose poles are related to the plane of reflexion or refraction. The light has properties and characters which are not possessed by that which reaches us directly from luminous bodies." And again: "The angle of incidence and refraction follows neither the order of refractive powers, nor that of dispersive powers, but is a property of bodies independent of other modes of action which they exercise over light."[1]

These observations, embracing, as they do, only a small part of the truth, are suggestive of new difficulties, rather than explanations of known ones. They leave the chief question unresolved: a circumstance which can only be accounted for on the supposition that the hypothesis of Malus had been received without due examination, simply on the ground of its popularity: a test not always to be depended upon.

No doubt can be entertained that the element of light, whatever be its intrinsic nature, enters freely into combination, mechanically or chemically, with every substance in

structure of the eye, unless the two pupils be maintained in a perfectly horizontal position at the moment of measurement, the results cannot be depended upon. I likewise shewed that the observance or non-observance of this condition, as to the position of the two pupils, all other things being the same, constitutes the only difference between a good and a bad marksman with a gun, and especially with the rifle at long ranges. I have therefore little doubt that this is the cause of discrepancy, in regard to the four observers to whom the Astronomer Royal refers.

[1] Ejusdem, p. 487.

nature. Nor can it, with propriety, be doubted, that in some way those substances re-act upon light itself: it being a law in physics, that action and re-action shall follow each other as cause and effect. Now, one of these effects results in the development of colour, under the mutual influence of *lateral shadows* and *light of collateral irradiation.* This effect is rendered most perceptible when displayed in the coloured brightness of clouds, and in the gorgeous tints of the morning and evening skies.

Another result arising out of this mutual action and re-action appears to be intimately associated with the elements of heat, air, and moisture, in connection with motion. These are, indeed, the grand causes of physical change; of decay and reconstruction: *corruptio unius est generatio alterius.* The world grows old and is rejuvenated hourly under their combined action: the great laboratory of Nature is never at rest, the sources of electricity never dried up. And till the principle, therefore, of what may be termed *personal electricity* shall be systematically investigated, even though we transport our thoughts along the speaking-wire to the most distant parts of the globe, we shall still be ignorant of the latent causes of disease, and of the often insidious approach of our corporeal dissolution.

Exp. 25. Having placed a decanter on a table, covered with a white cloth, immediately in front of a single window, I perceived that the former projected three shadows upon the cloth; namely, two laterals, and one primary. The former were in perspective projection with the two sides of the window; but the latter, being the resultant effect of the other two, and caused by their mutual overlapping behind the decanter, the dark triangular shadow represented in the diagram thereby appeared in view. And as these two laterals were projected from the decanter by the light which entered the immediate sides of the window, the former naturally expanded. And since the central portion of the light produced no sensible effect of shadow, therefore X may be considered the *neutral* point of the window. Now, as the central shadow is composed of corresponding sections of both laterals, and combines the

depth of each, it is necessarily twice as dark as either shadow singly. I have therefore, on this account, denominated it, and all similar ones, as the *primary*. Thus, in the present diagram, let A B represent the two sides of a window; *a b*, a decanter; a' and b' the lateral shadows of the latter, projected by A and B respectively. And since the laterals a' and b' cross at a point immediately in the middle of the decanter, and that corresponding sections of the shadows a' and b' cover the same area behind the decanter, therefore their juncture produces the central triangular shadow *a* C *b*, to which, as above stated, the term *primary* has been given.

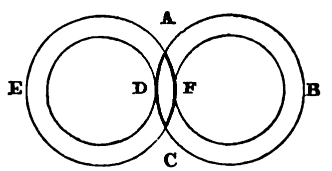
Now, at *a* and *b*, the point of impact of the radiants A and B respectively, there are no lateral shadows. At *c* and c', they are undistinguishable by reason of their narrowness, and of the powerful stimulus produced upon the eye by the dark primary, with its sharply-defined edges, *a* C, and *b* C, as contrasted with the whiteness of the cloth. But at *e* and e', the primary being at that place only half as broad as at *c* c', and the laterals of double the breadth, the latter became very distinctly visible. At C, the apex of the triangular primary (at which point the latter effect ceases), the laterals acquire at that place their greatest breadth, and, as it were, take the place of a primary or central shadow. From this point likewise they divide, and branching off into two different directions, and spreading laterally as they advance, they gradually cover a broader surface; and each, therefore, thus becoming fainter and fainter, they at length fade away, at the distance of about three times the length of the primary shadow from C, and become obliterated by direct light from the window. If the day be obscure, the external portions of the laterals, both before and after division at C, will gradually soften into direct

light, leaving their interior edges marked by strong dark lines as deep nearly as the primary, out of which they will appear to spring. This will give to the former that remarkable appearance which characterizes the arches of the luminous circles in Grimaldi's experiment (about to be given), in which, though paradoxically, a body actually illuminated becomes more dark by having a new light added to it.

These lateral shadows, however, when single, are never of uniform depth, being fainter at those portions which are the nearest to the edges *a* C and *b* C. This want of uniformity is caused by the light of collateral irradiation, which, flowing from the radiants A and B, after impact on *a* and *b*, is deflected, and, falling upon the lateral shadows *a′* and *b′*, near to *d* and *d′*, these portions become partially illuminated. By this distribution of collateral light, the primary shadow appears to be really darker than in nature; and while positive blackness is hereby avoided, the parts in actual shadow receive sufficient illumination and relief, in regard to detail, from the subdued light of collateral irradiation indirectly reflected upon them. By this contrivance, also, we are enabled, on the third and fourth day after each new moon, to behold portions of her surface unilluminated by direct solar light, which would have been veiled in darkness had not the *light of collateral irradiation* from her own surface supplied her with a "twilight" derived by reflexion alone from her own atmosphere. For it seems incredible that, at the distance of 240,000 miles, the light reflected by the earth to the moon could, by a re-reflexion, produce any appreciable effect upon our organs of vision. In making these remarks, however, I must express a hope that I may not be included among those upon whom an able writer has passed a severe censure for objecting to Dr. Young's "Law of Interference," in these words: "It is a "law which, though neglected at the time by many philo-"sophers, and opposed by the ignorance and jealousy of others, "triumphed over all opposition, and is now universally ad-"mitted as a general principle in physical optics."[1]

[1] Edinburgh Encyclop. Art. Optics, upon Dr. Young's Law of Interference, p. 555.

The proposition of Grimaldi lately referred to is this: "that a body actually illuminated may become more dark by adding a new light to that which it already receives."[1] To prove which, he made this experiment. Having bored two circular holes sufficiently near together in a shutter, and allowing two cones of light to pass through them into a darkened room, he received their bases on a sheet of white paper held at certain measured distances from the apertures. He thus found that the two bases of the lucid cones slightly overlapped each other, as shewn in the diagram, where A B C D and C E A F are the two luminous circles in question, of which A D C F represent their common segment. On closing one of the apertures, Grimaldi found that the central portion of the circular base was the part most strongly illuminated; and that the light diminished as the distance from the centre increased. "When, however, "both apertures were open, the common segment of the inter- "secting circles, A D C F, receiving a double portion of light, "became more luminous than the other portions of the base of "each cone; but *the two arches* A D C *and* A F C *presented* "*a remarkable degree of obscurity*, although they received more "light than the rest of the circumference of which they formed "a part. Now, if the paper be brought nearer to the aper- "tures, so that the segment A D C F may be diminished, a "position will be found in which the arches A D C, A F C, "will become *red;* but if the paper be withdrawn from the "apertures, so that the segment A D C F may increase in "diameter, the arches A D C and A F C will become more "and more obscure."[2]



Now, in the above statement it does not appear to me that Grimaldi entertained a clear conception of the true character of

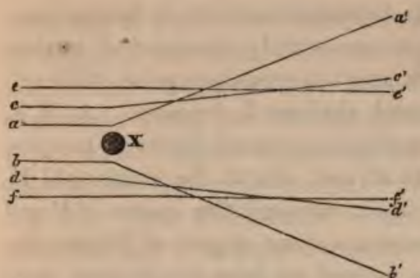
[1] Edinburgh Encyclop. Art. Optics, upon Dr. Young's Law of Interference, p. 551.

[2] Idem, p. 551.

the phenomenon which he described; or that he was conscious of the fact that the "luminous cones," by crossing each other before their bases were received on the paper, produced, at the central point of decussation of the cones A E C F, A D C B, the red colour of which he speaks. That point, however, may be called *the point of inversion* of the cones, as has been already explained in Exp. 23, 24, and 25. Now, this *remarkable degree of obscurity* of the arches A D C and A F C, to which Grimaldi alludes, was not produced by inflection or diffraction of light, as he supposed, but by *lateral shadows* from opposite and corresponding edges of the apertures, although the remaining portions of the included section, A D C F, had become illuminated both by direct light and by the *light of collateral irradiation.*

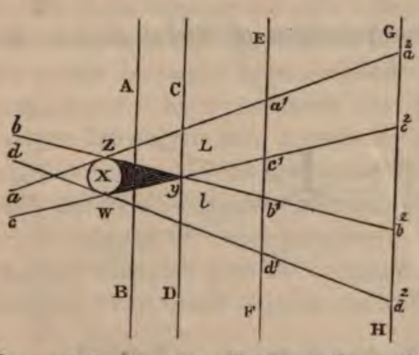
The labours of Grimaldi were not completed at the time of his death; but Sir Isaac Newton, struck perhaps by the novelty of their results, took up the subject, and carried it on, from time to time, up to the period of his own death, but not to completion.

The experiment which appeared to Sir Isaac's mind to be conclusive, as to the supposed law of diffraction, was as follows: he admitted a beam of solar light through an aperture (made in the shutter of a dark room) the 42nd part of an inch in diameter, and having fixed a human hair, the 280th part of an inch in diameter, across the aperture, he received its shadow upon a sheet of white paper, which he held at distances varying from three inches to nine feet from it. He, however, found a great disproportion in the width of these shadows, they being broader where they should be less broad, and narrower where they ought to have been broader. And relying on these results, he appears at once to have adopted Grimaldi's views on light. For, he says, if X be the section of a hair, and *a c e* represent three rays passing it on one side, and *b d f* three rays passing it on the other side, then the power of repulsion possessed by the hair will turn aside the ray *a*, nearest to X, and *before contact* with the latter, into the direction *a′*; the ray *b*, being more distant, and therefore less under the influence of the law of repulsion, to *c′*; but the ray *e*, being



too distant to be affected by the repulsion of X, will pass forward in a parallel line to *e′*. Simultaneous results will take place on the opposite side of X, in regard to the rays *b*, *d*, and *f*.[1]

Now a mere inspection of the diagram would almost suffice to shew that the true character of the phenomenon was not fairly represented; and I apprehend that, had the case been reconsidered, it is highly probable that Newton would never have put the question "Are not the rays of the sun reflected, refracted, and *inflected* by one and the same principle?"[2] The argument does not seem to be borne out by the facts adduced: on the contrary, they appear to establish the principle of *lateral shadows.* For let X in the following diagram be the section of a human hair, as in Newton's experiment; then, according to Exp. 25,[3] if a sheet of paper A B be held at the distance of two inches from X, the former will receive three shadows; namely, one primary, and two laterals: the former diminishing, the latter expanding. And notwithstanding the apparent disproportion between the widths of the



several shadows at the various distances from the aperture, to

[1] Edin. Encyc., Art. Optics, p. 553.
[2] Imperial Dict., word *Inflect.*
Ante, p. 12.

which Sir Isaac refers, this disproportion is really harmonious, for the two kinds of shadows are strictly symmetrical in their seeming inequality. Thus at y, the vanishing point of the primary X y Z, only the lateral shadows L l remain. At E F, the divided laterals will appear, to a casual observer, to cover the whole space from a' to d', and also at the distance G H, the whole space from a^2 to d^2, although the spaces c' b' and c^2 b^2 respectively will receive a certain degree of illumination from collateral irradiation, as well as from direct light, since neither the primary nor the lateral shadows cover those immediate places.

Again, in regard to the celebrated knife-blade experiment,[1] of which a single result was deemed to be sufficient to establish the hypothesis, That a beam of light is repelled by the surface of a reflecting body even before the former has come into contact with the latter: without introducing Newton's diagram, it may be sufficient to say, that he admitted for the purpose a beam of solar light through a minute aperture, in the same way as he had done in regard to the hair experiment; and that he found, as he supposed, that on his advancing the edge of a knife to the solar beam, it repelled the latter before it touched the knife-edge, and thereby turned it aside from its true course into the direction indicated by his diagram.[2]

Now, on the principles of *lateral shadows* and *collateral*

light, the following explanation of the phenomenon may be given. If a ray a enter a dark room through a minute aper-

[1] Walker's Lectures, Art. Optics, p. 110.
[2] Idem.

ture, and a knife-blade X be advanced sufficiently near to it to intercept the lateral ray *b*, the ray *a* will still proceed to *a′* and the ray *c* to *c′*; but if the knife be yet further advanced, so that *a* and *b* may be intercepted, then *c* only will fall on the paper at *c′*. Again advancing the knife, so that *c* likewise may be intercepted, then no direct light will fall on the paper *b′ a′ d′ c′*. But if the knife be drawn back a little, so as to allow the ray *d* to pass, the latter will fall at *d′*; and if the observer be not sufficiently on his guard against the illusion, he will assuredly fancy that the ray *a* had, by a special act of repulsion on the part of the knife, been turned aside to *d′*.[1]

Nothing is more difficult to eradicate from the mind than a preconceived opinion, especially when circumstances arise which appear to give to it an additional affirmation. On these occasions we believe too much, and too readily: *quod volumus facilè credimus.* Thus, in the case of Grimaldi, his views on inflexion of light having found partial favour, experiments were made with too little caution, with a view to their establishment in the popular belief. But in an analytical process of this nature, the principle under treatment should be tested by one or more examples of an opposite kind; so that, counsel being heard on both sides, and the question at issue fairly and judicially discussed, an impartial verdict may be returned. Sir Isaac appears to have completed the first part of the process; and had his valuable life been spared, I have no doubt that he might have complied with the other condition, and thereby have reversed his former judgment. He might have even seen a necessity for modifying the statement,.that "a ray of light has two opposite sides upon which the usual refraction depends, while the other two opposite sides are not endowed with that property."[2]

A strong analogy exists between the operation of vision with two eyes, in regard to external objects, and the illuminating

[1] All the diagrams in this Essay are greatly exaggerated, it being intended, in most cases, to appeal to the understanding through the eye, by an exhibition of glaring instances and effects of the *principle* involved in the particular case.

[2] Edinburgh Encyclop., Art. Optics, p. 477.

effect of direct solar light. No one was more observant of natural appearances than Leonardo da Vinci, upon whom an opportunity of improving his art was never thrown away, or lightly regarded. In one of his many propositions, he shews "why the most perfect imitation of Nature cannot have the same relief as Nature itself;" for, says he, "if the eyes A and B look upon the object C with the concurrence of both the central visual rays, A C and B C, I say, that the

sides of the visual angles (which contain their central rays) will see the space G D behind the object C. The eye A will see all the space F D, and the eye B all the space G E. Therefore the two eyes will see behind the object C all the space F E; for which reason the object C becomes, as it were, transparent, behind which nothing is hidden."[1]

Now, *mutatis mutandis*, if A B represent the horizontal diameter of the sun, then the whole space E F, behind the opaque body C, receiving direct light from the sun, will be illuminated, so that not only will C become, as it were, transparent, but, operating as a powerful reflector, it will actually increase the intensity of the direct solar light, by the concentration of its rays by *collateral irradiation*, upon that spot. And therefore the space E F, behind the opaque body C, will become more strongly illuminated than if the latter body had been absent.

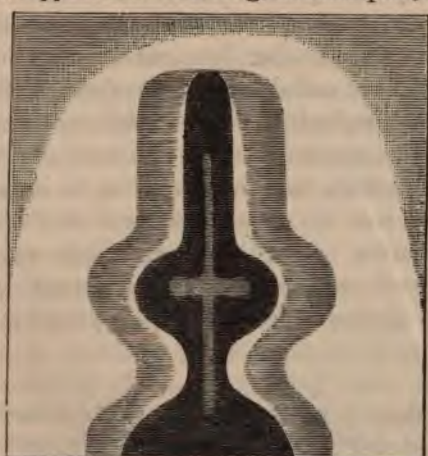
It must be evident, therefore, that the principle involved in the above experiment has a far more extensive and important application to physical optics than Leonardo had supposed. And I trust that the following examples will prove sufficiently interesting to induce other inquirers to attempt, by an application of the same principle, the solution of many similar phenomena, which have not yet received satisfactory explanations.

While walking one day in August with my brother, the

[1] Treatise on Painting by Leonardo da Vinci. Translation, p. 197. London, 1802.

Vicar of Hayling Island, Hants, my attention was drawn to a remarkable phenomenon. The locality was the South Downs of Sussex, near Beacon Hill, immediately above the village of Harting. The sun was about 20° above the western horizon, and the whole of that part of the hemisphere suffused with a warm glow of light.

At the time and place to which I am referring, my shadow reached to the distance of about forty feet, and, falling on ground nearly level, it appeared narrow, but, at the same time, to be attended by several lateral shadows, the same in number on each side of the principal shadow, so that the width to which the laterals spread seemed, in some measure, to compensate the narrowness of the primary. All the contours were alike. Between the laterals a glow of subordinate light appeared, into which they softened, leaving the several edges well defined. The same light also separated the primary from the nearest lateral on each side. But this glow, extending beyond the outer laterals, and falling on ground already illuminated by the direct rays of the sun, the additional light gave to the particular spot at which it appeared a most dazzling brightness. The dark shadow of the body of the hat presented the appearance of a long, slender pole, while that of



the brim seemed to hang across it like a shield. Just in the middle of the dark shadow of the hat and neck a cross of light was

faintly indicated.[1] After a good deal of examination, I perceived that the principal, or dark shadow, was formed by the overlapping of the two nearest opposite laterals, so that the included or common section, combining at that place the shade of each lateral, presented the phenomenon of a dark central shadow, embedded in the midst of a number of faint laterals, as represented in the diagram; in which, however, to avoid confusion, I have introduced only two opposite laterals, with their common section, and the luminous cross within it. There were, however, at least three more lateral shadows than I have represented on each side of the primary. The entire group was also involved in, and surrounded by, the halo of light above described. The laterals, like those in Exp. 24,[2] extended over the top of the primary; but the distance at which they fell was too great for me to perceive in what manner they did so. It was, however, sufficiently obvious, that had the glow by which the laterals were enveloped and surrounded not been reduced in brightness by this mingling of their subordinate shadows with the light itself, the portions of the halo within their immediate range would have been as luminous as the glow by which the whole group was environed.

I made many attempts to discover the cause of this brilliant appearance, and at length satisfied my mind that it arose primarily from direct solar light, which, after impinging on the edges of the hat and shoulders, was thence deflected, at the *angles of total reflexion,* so as to fall with its associated shadows in the manner and at the place above described. The halo in question, therefore, both as to its external and internal unity, was the immediate result of the *light of collateral irradiation.* And the internal halo was less bright than the external one, only because its strength was subdued by the lateral shadows through which it passed in its progress into the valley.

[1] This effect shews in what manner subordinate collateral illumination is carried into the deepest shadows; and it is in the management of this kind of chiaro oscuro that the judgment and skill of the painter are chiefly shewn: yet what writer upon Art has heretofore noticed it?

[2] *Ante*, p. 8.

When a similar phenomenon was beheld by Benvenuto Cellini, in one of his journeys, his vain and arrogant mind became so impiously inflated by the vision, that he thus records the rapturous state of his feelings: "This (the exterior halo) is one of the most extraordinary things that ever happened to man, and I mention it in justice to God, and the wondrous ways of His providence towards me."[1]

The student of nature (as well as the anatomist) should direct his attention to these effects of *lateral shadows*, and *light of collateral irradiation;* for the former, by laying his deeper shades on a somewhat paler ground than the general tone of the locality on which they are intended to fall, will avoid the disagreable effect of blackness which disfigures many paintings. And by introducing delicate lateral shadows, as auxiliaries, he will also avoid those meretricious but conventional tricks which are the usual attendants upon poverty of design and defective drawing. Although these two principles were not *theoretically* understood by the best of the old masters, they were *practically* followed out by them in their chief productions, as may be seen in works by Titian, Paul Veronese, Correggio, Murillo, Rubens, Rembrandt, Vandyke, Ruysdael, Teniers, Le Nain; and even by many modern masters, as Sir J. Reynolds, Wilson, &c. When the same principles, however, were carried beyond their legitimate bounds, the practice degenerated into such affectation and mannerism as usually characterize the school of Caravaggio, and even that of the Caracci; the concomitants being blackness, hardness of outline, absence of demi-tint, of grace, of nature, and of sobriety of expression.

But a still more startling effect of collateral irradiation awaited me than any which I have yet described; for on again ascending Beacon Hill with my brother, by a spur rising from its south-west side, at about 5 P.M., the western sky being still in the same glowing state as before mentioned, I arrived at a position from whence my shadow, extending across the valley, reached to the distance of about

[1] Benvenuto Cellini's Memoirs. Translation, vol. ii. p. 56.

two hundred yards. Though fainter than before, it was surrounded by a brighter halo, which latter, however, occupied a much larger space than on the previous occasion.

Having remained a sufficient time on the spot to assure myself as to the more striking points of the phenomenon, I re-commenced my ascent of the hill, and on reaching a more elevated spot, I observed that my shadow in the valley, now projected to the distance of about five hundred yards from me, was entirely changed in appearance, it being double. Both shadows were of the same size, both faint, and both alike; and the space between them, as far as I could judge at that distance, might be about twenty-five or thirty feet. At first I supposed my brother to be near me, and that one of the two shadows must have belonged to him. I therefore naturally turned to speak to him; but he was nowhere to be seen. I then moved about from place to place, the more effectually to examine so remarkable an appearance, and to satisfy myself as to its reality. The halo, too, which had accompanied the single, now overspread the binary, shadow, and rendered it more distinct: it likewise covered a much larger space of ground.

As my brother soon afterwards approached, I carefully watched the effect of the conjunction of our respective binary shadows. I remarked that, as his two shadows glided slowly over mine, each of the latter was darkened by the operation. But when he remained stationary, at the distance of a yard from me on my *left*, our respective double shadows having crossed at an invisible point in the atmosphere situated somewhere between the place on which we stood and the valley on which they fell, they re-appeared in the following order; namely, our two nearest shadows covering the same area, produced by their junction one dark central or primary shadow,

while his other second shadow, standing apart on the *right* of the latter, and my other second shadow apart on its *left*: both being divided by the same distance, they presented the phenomenon of a triple shadow, as shewn in the diagram. The two outer shadows,

however, being single, were still faint as before, although a bright halo spread around the groups.

We now changed sides, my brother passing over to the *left;* during which operation his double shadow, corresponding to the movement, likewise crossed over to the opposite side to that on which it appeared before, as well as contrary to that on which he himself stood; and, he being again stationary, the same phenomenon was repeated of a triple shadow, exactly like that which appeared before our change of place, but inverted as to position.[1]

We once more separated, and on my arrival near to the summit of the hill, from whence a much more commanding view of the valley was obtained, I looked into the latter in vain for my two shadows: they nowhere appeared; but, at the proper place for them, a dazzling halo or spot of light was seen, which, though falling on a place well illuminated by the sun, and reaching to the distance of eight or nine hundred yards from me, seemed, by its dazzling brightness, to throw the whole valley into deep shadow. The area now occupied by the luminous halo might be about fifty feet in height by forty in width.

It is scarcely possible to conceive a spectacle more grand and imposing than the phenomenon above described. Such, indeed, was its exceeding brilliancy, that the effect became dazzling to the eyes. It seemed as though the solar spectrum had been transferred to the spot by the action of some powerful reflector, or concentrated there by some equally powerful refracting lens; and while musing upon the phenomenon, and the probable nature of its cause, the following lines came naturally to my recollection:

> "And as the centre of some convex glass
> Draws to a point the congregated mass
> Of dazzling rays, that, more than nature bright,
> Reflects each image in an orb of light,
> While from that point the scattered beams retire,
> Sink to the verge, and there in shade expire."[2]

[1] In the present diagram only half-length shadows are represented, as the outline of the hill itself intercepted the other parts of the figure.

[2] Du Fresnoy's Art of Painting. Mason's Translation, ver. 389, &c.

It also reminded me of a similar phenomenon to which Lucretius alludes: "They say," he states, "that from the lofty hills of Ida the rays of the sun, when his light appears in the east, seem to be dispersed, but are afterwards collected, as it were, into one body, so as to form a complete orb.[1]

The phenomenon to which Lucretius refers is evidently that which Diodorus Siculus describes in the following passage: "It happens that a peculiar and strange thing takes place in reference to this mountain (Ida); for at the rising of the dog-star the sun seems, while it is yet night, to send upwards his rays when the air is tranquil, not in a circular form, but having its beams scattered into several places at the same time, as if many fires rested upon the horizon. But, after a little while, these fires are brought together into one place, apparently about the size of three acres (τριπλεθρον). And as the day advances, and the sun has risen into full view, his appearance then determines the character of the day.[2]

No doubt remains on my mind that the cause of the above-mentioned phenomenon is entirely due to *lateral shadows* and *the light of collateral irradiation*, which (the mists of the early dawn receiving them from Mount Ida) are reflected in the manner above described. Moreover, the period of its occurrence is particularly specified, namely, August, at which time of year, in the latitude of that locality, the rising of the dog-star pre-

[1] "Quod genus Idæis fama'st e montibus altis
Dispersos igneis orienti lumine cerni;
Inde coire globum quasi in unum, et conficere orbem."
Lucretii, lib. v. ver. 662, &c.

[2] "Ιδιον δὲ τι καὶ παράδοξον συμβαίνει γίνεσθαι περὶ τοῦτο τὸ ὄρος, κατὰ γαρ τὴν τοῦ Κυνὸς επιτολὴν ἐπ' ἄκρας τῆς κορυφῆς διὰ τὴν νηνεμίαν τοῦ περιεχοντος Ἀερος ὑπερπετῆ γινεσθαι τὴν ἄκραν τῆς τῶν ἀνεμων πνοῆς· ὁρᾶσθαι δὲ τον ἥλιον ἔτι τῆς νυκτὸς οὔσης ἀνατελλοντα τὰς ἀκτινας οὐκ ἐν κυκλοτερεῖ σχήματι τετραμμένον ἀλλὰ τὴν φλόγα κατὰ πολλοὺς τόπους ἔχοντα διεσπαρμένην, ὥστε δοκεῖν πυρὰ πλείω θιγγάνειν τοῦ τῆς γῆς ὁρίζοντος. Μετ' ὀλίγον δὲ συνάγεται ταῦτα πρὸς ἐν μέγεθος, ἕως ἂν γένηται τριπλεθρον διάστημα, καὶ τότε τῆς ἡμέρας ἐπιλαβούσης, τὸ φαινόμενον τοῦ ἡλίου μεγεθος πληρωθὲν τὴν τῆς ἡμέρας διαθεσιν κατασκευάζει.—Diodorus Siculus, lib. xvii. p. 491.

cedes that of the sun by some few minutes. That the state of the atmosphere was also connected with the phenomenon, may be gathered from the concluding part of the passage.[1]

After a careful consideration, therefore of all the circumstances, I feel no hesitation in deciding that the phenomenon witnessed from the top of Beacon Hill was the result of solar light deflected collaterally from the bodies of the two observers, and thereby projected to the place in the valley at which the bright halo appeared. But as it might be difficult, and in some cases impracticable, to ascend high hills for the purpose of verifying the accuracy of the above statements, a more easy mode will be found of witnessing the co-ordinate phenomena, though, of course, less perfectly, by resorting to the following experiment: namely,

Exp. 26. Let a sheet of white paper be raised vertically before a single window, at the distance of about ten or twelve feet from the latter. Then let a cedar pencil be held upright immediately before the illuminated side of the paper, so as just to touch its surface. This done, a strong, dark, and rather narrow shadow, falling at the place of contact, will be observed by looking at the reverse side of the paper. There will appear also two fainter shadows, one on each side of the dark one, though considerably broader than the latter; their outlines, however, will be imperfectly defined. Now, it will be found, on close inspection, that these laterals are formed by

[1] While this MS. was preparing for press I received No. I. vol. xvi. Nov. 9, 1855, of the Royal Astronomical Monthly Notices, in which I find, at page 16, some remarks which bear strongly upon this subject. They are by Baron Humboldt, in allusion to a letter written by the Rev. Mr. Jones, chaplain of the United-States steam-frigate "Mississippi," containing the results of observations, made on board that vessel, on the zodiacal light, and published "in Mr. Gould's valuable American Journal, No. LXXXIV., May 26, 1855." By (of course) an unintentional omission on the part of the Baron, the dates of observation of Mr. Jones appear to be omitted. I have no doubt, however, that the phenomenon referred to by both these gentlemen is the same in character as that described by Diodorus Siculus, and caused by *lateral shadows* and *light of collateral irradiation*. This I shall again refer to in its proper place.

rays of light which, entering at the two sides of the window, and crossing each other immediately, as it were, in the middle of the pencil (as in the decanter experiment),[1] project the two lateral shadows in question. As, therefore, these laterals mutually intersect each other to form a common section or central shadow, hence a recurrence of the same phenomenon as was seen from the spur of Beacon Hill. And since, also, lateral rays were deflected from corresponding sides of the pencil, the former, being thereby partially illuminated, have their external edges faintly and indistinctly defined.

By removing the pencil gradually from the paper in the direction of the window, the lateral shadows will be made wider and, consequently, the central or primary shadow, becoming narrower and narrower, will gradually dwindle to a mere dark line. And when, by the continual receding of the pencil from the paper, the laterals appear to be on the very verge of separation, a succession of subordinate shadows will appear to issue out of the waning primary, and, closely following each other to the right and to the left in quick succession, and in equal numbers, will, on arriving at the distance of about two inches from a middle point, simultaneously disappear at both those places.

Meanwhile, a glowing light or halo will be seen to surround the shadows of the pencil, and, extending to some distance, will form a luminous arch above their summits. This luminous halo will become brighter according to the quantity of light collaterally deflected from the pencil, and cast on the paper.

If now the pencil be made to recede in the slightest degree further from the paper, the laterals will immediately separate, and form two distinct and equal shadows, so that the space between is as well illuminated as the part without them. By moving the pencil still farther from the paper, the central clear space will increase in width in the same ratio as the shadows retire; and when the latter shall have receded from each other to the distance of about two inches, they also will disappear at those precise places, leaving the paper blank and uniformly illuminated.

[1] *Ante* p. 12.

If this experiment be fairly conducted, and the light admitted into the room be of a subdued character, it will afford very satisfactory and conclusive results, and, in conjunction with the other proofs, will establish, as physical truths, the co-ordinate principles of *lateral shadows*, and *light of collateral irradiation*. It will also shew that the statement, That light is actually repelled by the superficies of bodies before contact [1], is a fanciful notion, founded on a fallacy in vision.

The principle of lateral shadows, as herein set forth, and as exhibited from the top of Beacon Hill, may be briefly explained by the help of a diagram. Thus, let A B represent the horizontal diameter of the sun, D an opaque body on the side of the hill, *a′* the vanishing point of the lateral *a a′ b*, and *b′* the vanishing point of the lateral *b b′ a*, caused by conjugate radiants from A to O and B to O respectively. Now, since these laterals *a a′ b* and *b b′ a* cross each other behind D, and form a common section *a* C *b*, terminating at the point C: therefore, the resultant effect or central shadow, *a* C *b*, combining the depth of both laterals, becomes the primary of D.

Now, at *a* and at *b*, two opposite points of the surface of D, no lateral shadows will appear, as the direct solar rays from A to O and from B to O impinge on points contiguous to *a* and to *b* respectively. But at E *e* they become decidedly visible, having increased in width in the same ratio as the primary diminished. At G C *g*, however, the duplication of the laterals ceasing at the point C, the latter acquire at that place their greatest width. But from the same point also they begin to divide: therefore, at H *h*, say 500 yards from D, they become two distinct shadows; but at that distance likewise, though more spread, they are less effective for shadow, and therefore appear fainter than at any other

[1] Edin. Encyc., Art. Optics, p. 533.

point nearer to D. At b' and a', however, being 800 or 900 yards from D, and also the vanishing points for effective shadow of $a\ a'\ b$, $b\ b'\ a$, respectively, the laterals disappear, and D becomes, as it were, transparent, according to the definition of Leonardo da Vinci.[1]

But, as before stated, the space $b'\ a'$, having received a considerable accession of solar light by collateral irradiation from D, is so brilliantly illuminated as to cast into apparent shadow the whole of the other parts of the valley, although a bright sun shines directly upon them. Therefore, *mutatis mutandis*, if, in the following diagram, A 1 2 3 4 5 B represent so many radiant points of the surface of the sun, and D an opaque body, then the luminous matter emitted by the radiants A 1 2 3, after impinging on D at contiguous points to x, will be projected thence, at *the angles of total reflexion*, to other corresponding points at $a\ c\ b\ d$, of the valley $a'\ b'$; and by a simultaneous process, the radiant matter proceeding from B 5 4 3, after impact on D, at contiguous points to y, will be thence deflected at the *angles of total reflexion*, to other corresponding points at $b\ c\ a\ f$ of the valley $a'\ b'$.

But other luminous points between A 1 2 3, and B 5 4 3 will likewise emit luminous matter, which falling, in like manner, on other corresponding points of the valley $a'\ b'$, the accession of solar light there received by collateral irradiation should have been rendered nearly as brilliant as the sun itself. But since the radiants in question are as effective for lateral shadows from D, as for collateral irradiation from points contiguous to x and y; therefore these laterals so impoverish the collateral illumination, that the general effect of the *shadow-in-light* of D becomes only as bright as the halo seen from the top of Beacon Hill.

[1] *Ante* p. 20.

Perhaps one of the most remarkable features of the phemenon above described is this, namely, that the central point of the sun O (of the former figure) and 3 (of the present one) is that from which the smallest possible effect of illumination and of shadow is produced; so that, as in the middle part of the magnet, the centre of the sun's visible disc may be considered its *neutral point.*

Now the results of Experiments 24, 25, and 26,[1] in regard to the principles of illumination and lateral shadows, force upon the mind the conclusion, that the matter of solar light is thrown off, simultaneously, from opposite sides of the sun, only in lines tangential to his surface, and verging towards each other, as exhibited in the annexed diagram. For example, if E W represent a section of that luminary at the Equator, supposed for the argument to be at rest, then the conjugate rays proceeding from the side E and from the side W, and inclining towards each other, must cross and recross in all directions around the sun's body at angles varying in magnitude as the distance from his surface, and producing lateral shadows from intermediate bodies corresponding with those angles and the relative positions of those bodies. If the luminous matter flow from the side E in the direction E *e*, and also from the side W in the direction W *w*, they will mutually cross at the point C; and supposing the projectile forces to be equal, their resultant effect will lie between the two, namely, in the perpendicular from the point C. If the flow of matter take place from the side E in the direction E *e'*, and likewise from the side W in the direction W *w'*, their crossing taking place at C', the resultant effect would still lie in the perpendicular. Precisely similar results would follow from all other crossings, at whatever point they might occur. And since these mutual decussations would take place at points everywhere symmetrically distant from the solar surface, therefore, according to the above hypothesis, it is impossible that any one part of the sun's disc can exhibit a more luminous appearance than another. Not only will the central and circum-

[1] *Ante*, pp. 8, 12, and 27.

yet, as the conjugates cannot be brought to maturity for the production of light, in failure of this mutual crossing and exchange of polarities, therefore they are unproductive for the purpose of illumination. Hence we arrive at an explanation of another phenomenon, namely, the cause of the appearance and disappearance of periodical stars. For as none of the astral bodies maintain precisely the same relative distances apart, but sometimes approach nearer to, and sometimes recede farther from, each other (as Lagrange has proved),[1] according to the operations of a law, itself invariable, to which all the systems of the universe owe their permanency and stability: therefore, if E W be a star, and B the earth when at its mininum distance therefrom, then will E W be visible to the latter; but when the earth arrives at *b*, its maximum distance, E W will then be invisible to the former.

With these data in view, the principle of ***collateral irradiation*** may be applied in explanation of a number of cases analagous to those which have been already described; such, for example, as the corona of light seen at the moment of total eclipse on the 7th of July 1842, and again on the 28th of July 1851. On both these occasions the strongest mass of light appeared next to the dark body of the moon, but, gradually softening in brightness, it melted insensibly into the deep azure by which the corona was surrounded. This phenomenon, according to the principle of *collateral irradiation*, may be thus explained: Let A G represent the diameter of the sun at the moment of total eclipse,

[1] Edinb. Encycl. Art. Astron., p. 603.

and A B C D E F G so many radiant points on his surface from whence the luminous matter issues; M a section of the moon, and I the earth. Then, at the moment of superposition of the moon upon the sun, the luminous matter from A, impinging on the side of the moon at the points X and Y, will be thence deflected, at the angles of total reflexion, towards *a* on the left, and towards *a′* on the right, side of her disc; that from B to *b* on the left, and *b′* on the right; that from C to *c* and *c′*; and so on with respect to E F and G: the same effect also taking place from intermediate points. Thus, cross rays of solar light being *collaterally deflected* from so many points of the moon's surface, and flowing thence, as by a continuous stream, into so many corresponding directions of the lunar atmosphere, the action thereby produced would necessarily give rise to the phenomenon of a corona, such as that described by Sir John Herschel and by Mr. Main.

Another remarkable effect of the principles of *lateral shadows*, and *light of collateral irradiation*, is to be found in the appearances of the "*red* projections" seen during a total eclipse of the sun. Sir John Herschel gives an interesting account of this phenomenon, in his "Outlines of Astronomy;" and the Rev. Robert Main, M.A., gives an equally interesting description of a recurrence of the same phenomenon, in his "Rudimentary Astronomy." These accounts state that the "*red* projections," or "*flames*" as they have been sometimes called, resemble conical hills, having narrow bases; and that the perpendicular height of some of them has been estimated by Beer and Maedler at 40,000 feet, or about 14,000 feet higher than Chimborazo of the Andes. Now, hills of such stupendous elevation, as compared with the moon's diameter, would, if rising from her surface, give us a strange idea of the geological structure of that planet; and even if they belong to the sun, little as is known of that luminary, we should be disposed to receive the estimate *cum grano salis*. But I believe both the forms and the colours to be merely optical illusions; the former being *lateral shadows* of conical and other shaped hills, in all respects similar to those usually seen on the moon's surface, whose perpendicular elevations are

moderate, as compared with the *red* eminences of which we are speaking; and the latter, namely, the coloured appearances, being merely *shadows-in-light*, tinted by the *lateral shadows* of hills situated, probably, hundreds of miles beyond the moon's visible disc, on that side of the planet whose surface has never been directly viewed by mortal eye. For the development of such-like appearances, it is not necessary that the hills whose forms are presented to us only by their *lateral shadows* and *shadows-in-light*, should be more elevated, or different in character and shape, from those whose natural shadows we see, about the time of the moon's first quartering, projected upon her surface by hills of ordinary shapes. An inspection of the diagrams given by Sir John Herschel and by Mr. Main, in the title-pages of the respective works before mentioned, will, I apprehend, satisfy the most sceptical as to the cause of both phenomena being rightly ascribed to *lateral shadows* and *light of collateral irradiation*; being likewise analogous to, if not identical with, the causes which gave rise to the phenomenon observed before day-break around Mount Ida more than 2000 years ago; and also to that recently witnessed by myself from Beacon Hill, on the South Downs of Sussex.

Again, in regard to the *red* colour of the lateral shadows, or *shadows-in-coloured-light* projected by lunar mountains, such-like chromatic effects must mainly depend upon atmospheric reflexion. For colour, as such, having no separate or tangible existence, and being merely a modification of light by shadow (as will be presently shewn), cannot become visible in the absence of a reflecting medium. Hence, it would seem to

follow as a necessary consequence of the red appearances, that the moon is really surrounded by an atmosphere of her own, of some density, and, in many respects, not dissimilar in character to that belonging to our earth. The absence of visible clouds, and the other arguments usually adduced in support of a contrary opinion, appear to me to have no force, they being opposed to the conclusions from analogous cases. That her atmosphere accords with her geological condition must not be denied; and as she appears to have neither an ocean, nor rivers, nor fountains of water, upon her surface, we may presume that the constituents of which her atmosphere is composed may differ in some respects from those which compose our own, and from which we derive so much moisture. With us, certain definite results follow from the various proportions in which hydrogen, oxygen, nitrogen, and carbon, or their elements, combine; and slight variations in these respects would produce all the results required of, and exhibited by, a lunar atmosphere.

The zodiacal light appears to be another manifestation of the *light of collateral irradiation*, in connection with *lateral shadows*. It is, of course, best seen in tropical regions, because there it has the ecliptic nearly always for its axis: and likewise because the solar rays are deflected, after sunset or before sunrise, from parts of the earth's surface only a little below the observer's visible horizon, and in perspective projection with the place of the sun. And since the luminous matter, after impact, is thrown forward by collateral irradiation, and made to cross the observer's vertical at an extremely obtuse angle; therefore, while this circumstance renders the appearance of the light more brilliant by contrast with the obscure azure above its boundary, the rotundity of the earth and rapid motion on her axis generally obliterate the columnar brightness soon after sunset. Now the reverse of this takes place in high latitudes, where, about the times of the two solstices respectively, the solar rays are made to glance off by collateral irradiation, from parts of the earth's surface more obliquely, and from points more distant below the visible horizon, than in the tropics. And the luminous matter being more diffused,

and deflected upwards in larger quantities, and to a greater elevation, as regards the observer's vertical; the columnar light having likewise its pole directed alternately more to the north or to the south, according to the earth's position in her annual orbit, and to the apparent track of the sun: therefore the atmospheric illumination is here more extensive and more lasting. Hence, favoured by locality and by the sun's position, the inhabitants of our more northern and southern regions enjoy, during their respective summers, a more prolonged twilight, and, consequently, a longer day.

These remarks seem to be entirely borne out by Baron Humboldt's observations, who, though mistaking, as it seems to me, the cause of the phenomenon of the zodiacal light, says: "On the whole, the variations of the zodiacal light appear to me to depend upon variations inherent in the phenomenon, and upon the greater or less intensity of the luminous processes going on in the ring. *This is proved by observations in the Southern Ocean, which indicated an opposite light in the heavens similar to that seen at sunset.*[1]

Baron Humboldt's observations on the zodiacal light were made in March of the year 1803, in the Southern Ocean, while sailing from Callao in Peru to the Port of Acapulco in Mexico. On the 17th, 18th, and 19th of March, says the Baron, the latitudes varying between 12°. 9′ and 15°. 20′, NORTH, and longitude 104°. 27′ and 105°. 46′ west of Paris,

[1] "Cosmos," Vol. iii. p. 589. – I must here again revert to the Monthly Notice of the Royal Astronomical Society, for November 9, 1855, in which I find remarks "On certain appearances connected with the zodiacal light," by Baron Humboldt, with an immediate reference to certain observations on the same subject, made by the Rev. Mr. Jones, Chaplain of the United-States' steam frigate "Mississippi." Without going much into detail, it will be sufficient to say, that both the Baron and Mr. Jones advocate the hypothesis of a nebular ring of light, having the earth for its centre. Mr. Jones says, "That it is a ring, the unbroken continuity of my observations (during a period of two years) satisfactorily determines." But if any reliance can be placed on the hypothesis of *lateral shadows* and *light of collateral irradiation*, by which I have endeavoured to explain the phenomenon, the notion of a nebular ring must be abandoned as untenable.—See also "Life of the Humboldts," by Klencke and Schlesier, p. 171.

the zodiacal light appeared to have its base resting upon the sun, while the former was brighter than he had ever seen it before at the approach of the vernal equinox. "The vertex of the "luminous pyramid measuring 39°. 5′ above the sea-horizon, "inclined somewhat towards the NORTH, and *its brightness in-"creased and diminished progressively during five or six nights, "with the greatest regularity.* Its colour was not white, like "that of the Milky Way, but a *reddish yellow;* and any small "clouds near the horizon reflected upon this reddish ground a "lively *blue* light. One would almost suppose he saw a second "sunset in the east; for while the light was very bright in the "west, we constantly perceived in the east (and this is, beyond "doubt, a very striking phenomenon), a whitish light, which "was also of a pyramidal form. I am inclined to think that this "white light in the east was the reflexion of the real zodiacal "light at setting. BOTH ALSO DISAPPEARED AT THE SAME "TIME." (Monthly Notice, above cited, p. 17). "The varia-"tions in the brightness of the phenomenon cannot, according "to my experience," says the Baron, "be accounted for solely "by the constitution of our atmosphere. There remains much "still to be observed relative to this subject."[1]

Mr. Jones's observations are as follows: "Twice, near the "latitude of 23°. 28′ north, when the sun was at the opposite "solstice, in which position *the observer has the ecliptic, at mid-"night, at right angles with his horizon, and bearing east and "west,* I had the extraordinary spectacle of the zodiacal light, "simultaneously at both east and west horizons, from eleven "to one o'clock, for several nights in succession.

"At an early period I began to query whether the moon, "near its full, might not give a zodiacal light;" and subsequently, after making fourteen reliable observations, he found that this planet did so. On another occasion, he noticed a zodiacal light caused by the joint action of the sun and moon, which, overpowering the moonlight proper, *caused a decided stream of light to appear in the sky* within the zodiacal-light boundaries, although the moon was then *without* the boundary

[1] The italics are added to draw attention to the passages.

of this jointly-reflected light. "It seems to me," says Mr. Jones, "that these data can be explained only by the sup- "position of a nebulous ring with the earth for its centre, and "lying within the orbit of the moon." Great hourly *lateral changes* in the boundaries of the light were *caused by the observer's change of place*, in that time, as regards the ecliptic or axis of the zodiacal light. "That it is a ring," the reverend gentlemen remarks, "the unbroken continuity of my observa- "tions satisfactorily determines." "*I could get no parallax;* "*but, on the contrary, as we went* SOUTH, *the boundaries of the* "*zodiacal light changed with us to the* SOUTH among the stars; "and so, *vice versâ, towards the* NORTH, caused, doubtless, by "the ring's presenting new portions of its wide reflecting sur- "face to the sun's light."[1] (*Vide* Monthly Notice, before cited, pp. 19, 20.) The idea which appears to prevail in the mind of Mr. Jones is this; namely, that a nebular ring, somewhat similar in character and in appearance to the ring of Saturn, lying within the orbit of the moon, extends around our earth. But the rule of analogy is scarcely applicable to the two cases, for the ring of Saturn may be nothing more than solar light reflected from *interior* satellites, moving with such velocity around the planet as to produce only the impression of a luminous ring upon the retina of the eye.

The phenomenon of the aurora borealis and australis seems likewise to be a development of the *light of collateral irradiation,* in conjunction with the earth's lateral shadows after sunset. As to the noise of crepitation which some persons are supposed, and have themselves believed, to have heard, that, I apprehend, must be an aural deception. The fact, that filaments springing from the same pair of nerves are distributed alike to the ear and to the eye, shews how intimately associated those organs are with each other. Hence, what affects the one sense is frequently responded to by the other; and the involuntary sympathy they mutually exercise is frequently a source of mental error.[2]

[1] The italics are not in the original passages.

[2] Sir John Ross, upwards of thirty years ago, suggested that the cause

Now as like causes produce like effects, the phenomena of parhelia, paraselenæ, solar and lunar halos, rainbows, and such-like, are likewise to be attributed to *lateral shadows* and *light of collateral irradiation* acting upon media having at least two surfaces; and therefore, if these principles are founded in truth and nature, as I believe them to be, it cannot fail to awaken our surprise that such able writers and profound thinkers as Aristotle, Dion, Julius Obsequens, Cardan, Snellius, Hevelius, Hook, Gassendi, Des Cartes, Smith, and others, should have missed them. But discoveries are frequently made by accident, and these accidents happening alike to all, to the simple as well as to the wise, their proper applications are sometimes made by men of inferior powers of mind.

The next phenomenon to which I shall refer, as an exhibition of the principle of *collateral irradiation*, is that which relates to the Nebulæ, which, scattered over different parts of sidereal space, appear of various shapes; sometimes distinguishable only as patches of loose light, sometimes as spherical bodies, and of other recognised forms. These masses have been supposed by Huygens and Des Cartes to be "phosphorescent vapour," "luminous sidereal matter," or "star-dust," moving in vortices, and slowly condensing, by a process of refrigeration, segregation, and aggregation, into solid planetary bodies. But, it may be asked in the language of Lucretius, "unde æther sidera pascit?"[1]—('Whence comes the ether that feeds the stars?') Yet, to be consistent, the advocates of the "nebular hypothesis" should also, like the ancients, have insisted upon the eternity of matter and the fortuitous motion of its parts; because these elements are equally necessary to it, equally opposed to analogy, and equally repugnant to reason. But I am here trenching upon a subject reserved for treatment in the sixth part of this Essay.

which produces the aurora is probably a reflexion of the sun's rays from the coloured surfaces of angular blocks of ice in the polar regions, and from the under surfaces of circumpolar clouds. I quote from memory, not having his "Arctic Voyage" to refer to.

[1] Lucret., lib. i. ver. 232.

The greater number of the nebulæ[1] appear to be situated within, or on the borders of, the Milky Way. Sir William Herschel divided them into six classes; namely, "1. Those "which are decidedly resolvable into clusters of separate "stars; 2. Those which are not wholly resolvable, but "which apparently would be by the use of greater optical "powers; 3. Those which in his telescope shewed no trace "of resolution; 4. Planetary nebulæ; 5. Stellar nebulæ; and "6. Nebulous stars."[2]

"All the resolvable nebulæ," says Sir John Herschel, "exhi-"bit themselves, in telescopes of sufficient optical powers to "shew them well, as almost universally round or oval, their "loose appendages and irregularity of form being, as it were, "extinguished by the distance." And those "which shew no "signs of being composed of stars, would probably be com-"pletely resolved by a further increase of optical power; in "fact, this probability has been converted into a certainty by "the magnificent reflecting telescope constructed by Lord "Rosse, of six feet aperture, which has resolved, or rendered "resolvable, multitudes of nebulæ which had resisted all "inferior powers."[3]

In attempting to trace a physical effect to its proximate cause, perhaps the best method to be pursued is, following the rule of analogy, to institute a comparison between a known, and a similar, but unknown, phenomenon. In this way we shall generally arrive at satisfactory results. Ancient philosophers fell into extraordinary errors by neglecting the mode of investigation by comparisons; as when, attaching no importance to ascertained facts, some attempted to establish the hypothesis of a *plenum*, others of a *vacuum*. They made appeals to the understanding by an *argumentum ad judicium*, in which pro-

[1] Although the word *nebula*, as applied to clusters of stars, is an evident misnomer, we cannot dispense with it till the popular mind shall have become familiarized with the more appropriate term *cluster*, which, though not descriptive of the *appearance* of many of these bodies, is more in accordance with their nature.

[2] Main's Rudimentary Astronomy, p. 152.

[3] Outlines of Astronomy, p. 597.

cess, however, all the conditions were to be granted. Lucretius, for example, says "We perceive odours, but see them not approach; distinguish heat, or cold, or sounds, but not with our eyes. Nevertheless, *all things must of necessity* consist of a corporeal nature, since they possess the power of impinging on our senses, as *nothing excepting bodily substance can touch or be touched.*[1]

Now if, with regard to the nebulæ, we adopt a process of analogy, we must commence by establishing the fact, that certain known clusters of stars occasionally assume a nebulous appearance. Thus, when the Pleiades are seen in a clear sky with our natural vision, we perceive that the group is composed of separate stars; but when viewed through a thin vapoury mist, the group appears only like the usual patch of light exhibited by a "nebulous" body. When, however, we direct our view to the nebula marked 13 Messier, although there be no vapour in the atmosphere, it will appear only as a patch of light; yet, when seen through a telescope of greater optical power, it is at once resolved into "discrete stars." But to resolve, even partially, the nebula in the constellation of Orion, it requires the utmost extent of optical power of which we have as yet found the means of applying to it. Yet far beyond these nebulæ probably, and lying, as it were, at the extreme boundaries of artificial vision, other luminous patches, similar in appearance, may be seen, which, by the rule of analogy, we may consider as representing similar clusters of stars. And no doubt, were our visual perception sufficiently sensitive, we should see far onward amid the ethereal spaces other like luminous patches, which, fading in the immeasurable distance, are doubtless planetary bodies, swayed by the same laws of gravitation and motion as those which regulate the system to which we belong. And although the individual members of each group perform their unceasing and noiseless revolutions around their central primary, the direct rays of which may never have affected our mortal vision, yet, rising

[1] "Tangere enim et tangi, nisi corpus, nulla potest res."—Lucret., lib. i. ver. 299, &c.

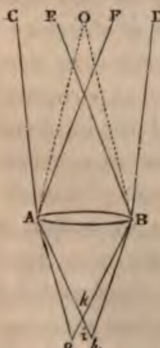
with the thought, and giving rein to the imagination, we shall behold in some of these groups systems far more stupendous than our own, the abodes, it may be, of beings of much greater intellectual capacities and of more refined feelings than any possessed by fallen Adam's race; into which abodes sin and sorrow may never have entered, in which no martyr's blood has been shed, and where, perhaps, the agonies of a Calvary may never have been endured.

Should it be asked, Why does a cluster appear to us merely as a patch of light, when the planetary bodies of which it is composed, and even the central luminary around which they revolve, can be seen in no other form? the obvious answer to be returned is, that such masses are not seen by direct light, but indirectly, by their *shadows-in-light* collaterally irradiated, in the same way as the *shadows-in-light* were projected into the valley from the summit of Beacon Hill. The cases are precisely analogous; the conclusion to be drawn from them clear and decisive: and therefore, since such groups are seen only by light collaterally deflected from perhaps thousands of opaque bodies belonging to a solitary system of stars, so, according to the perspective projection in which the common plane within whose limits they perform their periodicities is seen, the luminous masses, though seeming to be "almost "universally round or oval," will sometimes appear straight, hollow, double, spiral, and even as shapeless as the "Magellan clouds."

But the Milky Way is by far the most grand and extensive exhibition of all visible nebular phenomena. It includes within its boundaries the greater number of the astral clusters, each maintaining, it has been supposed, the same relative situation among the stars as in ancient times, and all extending, like a narrow zone, their common bow across the heavens. When viewed through powerful telescopes, it is found to consist apparently of millions of minute stars; so that it may be assumed, *à posteriori*, to mark, by the *light of collateral irradiation*, the luminous course of a solitary system of planets around their primary. If so, of what inconceivable extent must be this orbit, and of what stupendous magnitude the

central luminary? No stretch of the imagination can shadow forth an adequate notion of a spectacle of such sublime grandeur, in comparison with which all other similar systems fade into utter insignificancy. We can form no adequate conception even of the ages which it would require for any one of the planets of which this wonderful galaxy is composed to complete its periodical revolution. And how overpowering would be the light sent forth by *collateral irradiation* from the surfaces of so many myriads of stars, were the luminosity thereby resulting not reduced in brilliancy of effect by the counter-action of lateral shadows upon the deflected solar beams.

The operation of *lateral shadows* constitutes one of the greatest obstacles to the improvement of artificial vision; and it will, in all probability, greatly impede its advancement beyond the point at which it has already arrived. But not only do lateral shadows impair the efficiency of vision by artificial means, but even *the light of collateral irradiation* exerts a powerful effect in this respect; nor is it by the introduction of opaque diaphragms into eye-pieces that these properties of light can be counteracted. This subject, however, has been already discussed in Part III. of this Essay. I will only, therefore, in this place, explain the operation of *lateral shadows*, in regard to lenses.



Thus, in the present diagram, let A B represent the section of a double convex lens, C A E B and D B F A conjugate solar rays proceeding from opposite sides of the sun's disc, and incident at A and at B respectively. Now, if *h*, a focal point of A B, represent the left inverted half, C O, of the solar disc, and *g*, another focal point of A B, on the same plane as *h*, represent the other inverted half of the solar spectrum, D O; then these two halves slightly overlapping at *i*, will form a common section twice as strongly illuminated as any other part of the spectrum. For the lateral shadows *k h*, *k g*, issuing from their common point of decussation

at k, being projected into the directions $k\ h$ and $k\ g$, and falling on the half spectra h and g at their circumferential parts, will cause those portions to be lowered in brilliancy: hence the subdued effect of light at those places, which, to borrow an expression (though too loose for the occasion) from Dr. Jurin, forms there "*a circle of dissipation.*"

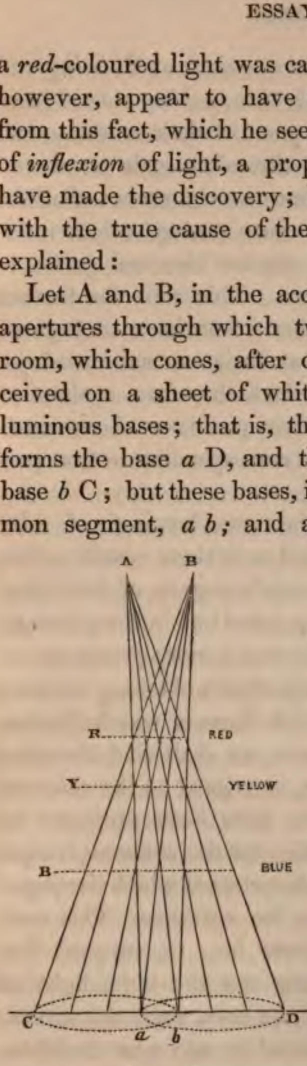
These effects may likewise be explained by a front projection. Thus, in the subjoined diagram, let 1, 2, 3, 4 represent four (out of innumerable) solar spectra, formed by conjugate rays emanating from opposite sides of the sun's visible surface, as in the last diagram. These conjugates forming inverted sections of the solar spectrum at 1 and 3, 4 and 2, respectively, and each section slightly overlapping the other, render the resultant effect at the centre C four times more luminous than at any other part of the combined spectrum. And since the sections *a b c d*, containing fewer rays, are less luminous than C, therefore these also are more luminous than the sections 1, 2, 3, 4, which contain the fewest rays, and answer, as before said, to the "*circle of dissipation*" of Dr. Jurin. But since, as shewn in the last diagram, the several points or crossings of the conjugate rays project their own shadows in the direction of the arches *a b c d*; therefore, the laterals thus falling produce the same "*remarkable degree of obscurity*" upon the conjugate arches *a c b*, *a d b*, and *d b e*, *d a e*, as were exhibited by the arches of Grimaldi's well-known experiment.[1]

Not only is distinct vision impaired by lateral shadows and the light of collateral irradiation, but these two antagonistic principles are likewise productive of a third cause of disturbance by their reciprocal action, by effecting an evolution of colour. For when Grimaldi received two luminous cones upon a sheet of white paper in a darkened room, he found, by holding the paper at various distances from the two apertures through which the rays passed, that at one particular distance

[1] *Vide* Edinburgh Encyclop., Art. Optics, p. 553

a *red*-coloured light was cast upon the paper. He does not, however, appear to have drawn any satisfactory conclusion from this fact, which he seems to treat as a spontaneous effect of *inflexion* of light, a property of which he is supposed to have made the discovery; but he was evidently unacquainted with the true cause of the phenomenon, which may be thus explained:

Let A and B, in the accompanying diagram, represent two apertures through which two cones of rays enter a darkened room, which cones, after crossing each other, and being received on a sheet of white paper, C D, form thereon two luminous bases; that is, the cone of rays passing through A forms the base *a* D, and that passing through B forms the base *b* C; but these bases, intersecting each other, form a common segment, *a b;* and as this common segment receives light from both A and B, it becomes twice as luminous as the other parts of the bases *a* D and *b* C. Now it was shewn in the last two examples, that the respective *arches* at *a* and at *b* exhibit "*a remarkable degree of obscurity*," having been caused by the projection of shadows from rays of light at the immediate points of their crossing at R, Y and B.



But these conjugate rays produce another effect at their points of decussation; for the place indicated by Grimaldi as that at which the *red* light appeared, must have been the immediate point R at which the central solar beams crossed, and at their crossing produced, by their luminous shadows, the colour of which he speaks. At the place of their second crossing at Y, where the space is more expanded, and, consequently, the light more diffused, a *yellow* colour should have appeared, as being the next in succession on the chromatic

[2] Loco citato.

scale. At the third point of their crossing, at B, being still more spread, and therefore more obscure, a *blue* should have been seen; but at C D, the fourth point of their crossing, and that at which the first series of the chromatic scale terminates and the second series commences, there a concurrence of all the lateral shadows taking place, would cause a mixed colour intermediate between *obscure red* and *obscure blue* and *yellow* to appear, resulting in obscure *indigo*. This will be further explained presently. But since other subordinate conjugates, coming in aid of the former, and at their mutual crossings, producing a general and a local effect, therefore a sheet of paper placed at any one of the four positions above mentioned will participate of the colour corresponding to that particular distance from the aperture.

Consequent, however, upon the overlapping of solar spectra in the manner above pointed out, there results a fifth effect, being the development, in a minor degree, of the "physical lines" which Fraunhofer first pointed out in the prismatic spectrum, and of which I shall have to say more presently.

If we compare the above chromatic effects of *lateral shadows* and *light of collateral irradiation* with those of which Newton gives a detailed account in his Optics, we shall find the same co-ordinate principles in operation, in regard to the *coloured shadows* or fringes stated by him to have been projected by a human hair and by a filament of silk; for the coloured fringes invariably followed the order of the distances at which the paper that received them was held from the aperture. This conformity of effect with distance induced him to suppose that the light admitted into the room was not the same light at all distances from the aperture; for, he says, since the several colours could not have been developed by any new modification impressed upon the rays by the hair, therefore "the "various *inflexions* by which the several sorts of rays were "separated from one another, which before separation, by the "mixture of all the colours, composed the white beam of the "sun's light; but, when separated, composed lights of the "several colours which they are originally disposed to exhibit."[1]

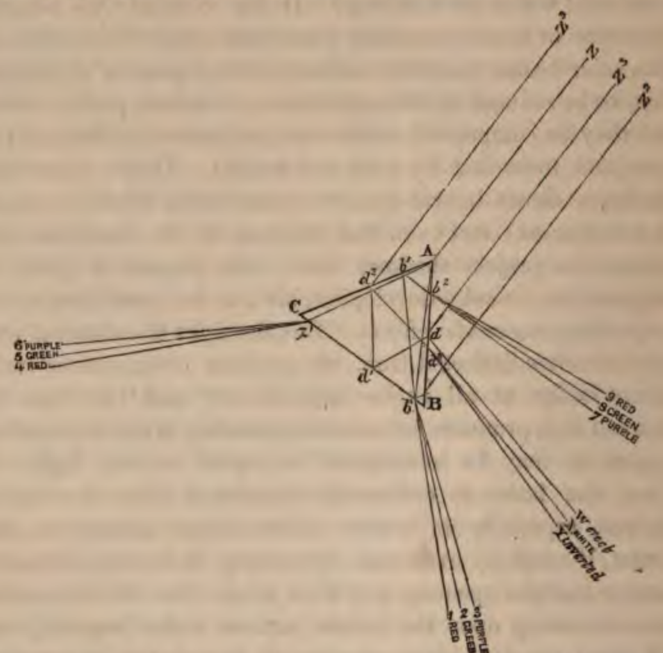
[1] Edinburgh Encyclop., Art. Optics, p. 553.

But in what manner can "the several sorts of rays" be separated from one another? or are they in any way separable from each other? Before this question can be answered, we must ask, WHAT IS COLOUR? It has certainly no separate existence or local propensity apart from shadow and reflexion. The solar beams cannot be submitted to a process of segregation, or be reduced by decomposition into minute parts; neither can they be compressed within narrow spaces, nor bounded by lines, nor measured by scale and weight. Direct solar light produces direct lateral shadows from bodies, whether opaque or transparent; and even the crossing of the luminous rays themselves project shadows from their respective points of decussation; thereby developing, also, as has been shewn, corresponding chromatic effects. But the light of collateral irradiation, when deflected from the surfaces of opaque or transparent bodies at all angles between 170° and 180° from the incident ray, produces colours corresponding to the intermediate angles, as may be ascertained in regard to solar light: for when the latter is collaterally irradiated from the earth's surface, especially in winter, either before sunrise or after sunset, if carefully examined by looking at the sky through a narrow upright opening, it will be found that the deep crimson-red resting upon the visible horizon melts insensibly into the deep purple which overspreads it and the intermediate landscape, while, above the former, it likewise softens into a brighter red, and this again into an orange, and so on, through the several gradations of *shaded light*, into a yellow, a green, a blue, a purple, and, finally, into the obscure azure of the higher regions of the atmosphere.

This doctrine, I fear, strikes at the root of the hypothesis of colour by the decomposition of solar light under the action of the prism, and equally consigns to the category of "OPTICAL ILLUSIONS" Fraunhofer's "physical lines of the solar spectrum," as I will now attempt to shew.

EXP. 27. In the accompanying diagram let A B C represent a triangular glass prism, of which the side A B is to be held in a vertical position in front of a single window, so that the

direct rays of the sun shall be allowed to fall immediately upon the sides A B and A C of the prism. Now, by following the direction of the ray Z, incident at the angle A, we shall



find it, after entering the body of the glass, branching off into two directions, *b* and *z′*, at which both respectively emerge, and, falling on two opposite sides of the room, form two equally distinct spectra; namely, the branch from *b* exhibits itself in the spectrum marked 1 red, 2 green, 3 purple; and that from *z′*, in the spectrum 4 red, 5 green, 6 purple.[1] On a close

[1] In this Experiment, the yellow, though extremely bright, occupies so small a space in the spectrum, in consequence of the blue extending so far over it in forming the green, that I have described the latter as taking the second place on the chromatic scale, instead of the yellow, the proper colour. Wollaston affirms that the primitive colours of the solar spectrum are only red, blue, green, and violet. *Vide* Watkin's portable Cyclopædia, Art. Light. Dr. Young, however, distinguished a narrow line of yellow between the red and the green. That this is true, the above experiment proves.

inspection of the colours, it will be seen that they are really composed of two separate spectra falling on the same plane, and covering each other in an inverted order ; so that the red of the one spectrum extending partially over the blue of the other spectrum, they together form the purple ; the blue of the one spectrum partially covering the yellow of the other spectrum, they together form the green ; and the yellow of the one spectrum falling partially on the red of the other, they together constitute the orange; and so on, by duplication, shading down at each extremity of the scale into a profound azure. Similar effects are also exhibited by the natural sky.[1]

Proceeding in like manner with z^2, incident at B, we shall find, that after entering the body of the glass, it takes a direct course to b, thence, by reflexion at the *angle-proper* to b', and by a re-reflection from the interior surface of the side A C at that place, it is thrown forward to b^2, and at that point emerging, forms an inverted spectrum at 9 red, 8 green, 7 purple.

But three other spectra, each colourless, will appear, namely, one from the ray z^3, which, incident at d, is reflected, at the *angle-proper*, to w white ; one from another portion of the same luminous matter-in-excess which, after entering the body of the glass, traverses it to d', is there reflected to d^2, at which point suffering a re-reflexion, it is thrown forward to d^3, and thence emerging, forms an inverted spectrum at Y. In like manner the ray z^3, incident at d^2, entering the body of the glass, traverses it to d', and after several re-reflexions at the *angle-proper*, from various points of the three interior surfaces, finally emerges at a point contiguous to d^3, and forms the third colourless spectrum X, immediately between the other two, leaving a clear unilluminated space between each of the insulated spectra.

By a slight movement of the prism on its axis, the inverted spectrum 9, 8, 7 will be made to descend; and, passing over the three colourless spectra (which, however, remain stationary during the operation), will cover the spectrum 1, 2, 3, in such

[2] *Ante*, p. 49.

manner as to render the three colours, red, green, and purple, more decided and clear. And as the limits to which the coloured spaces of the spectrum extend, in both directions, are well defined, their several edges are very distinguishable. By this combination of the colours of two spectra in an inverted order, the terminal tints become exactly alike; that is, the profound azure at one extremity receives into itself a deep crimson-blue; this again a crimson-red; and, in succession, an orange, a yellow, and a green. The green, followed by a purple, also gives place to a crimson-red, which again terminates at the other extremity in profound azure. But the intermediate colours, orange and yellow, occupying respectively only narrow spaces in the compound spectrum, being irrelevant, are not here particularly described.

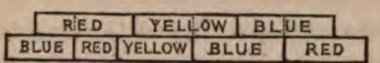
Now, in order to observe the effect of positive shadow upon these colours severally, I held a pencil before the two sides A B and A C respectively, so as to touch those surfaces, and thereby to cause the pencil-shadow to fall at the places required. Thus, upon the crimson-blue, the shadow was indicated by a richer colour of the same tint; and upon the red, orange, yellow, green, and so forth, corresponding effects of bright-coloured shadows were produced. But of all the *coloured shadows,* none was rendered so clear and free from impure or antipathizing tints as the green, the shadow being thereon of the most lively and rich colour.

This experiment appears to establish the fact, often stated in this Essay—1. That colour is shaded light; 2. That colour, divested of lateral shadows, is white light; 3. That white light is essentially white light under all circumstances; and, 4. That solar rays, although incapable of decomposition by the prism, nevertheless acquire colour by passing through coloured media, as well as by reflexion, refraction, and shadow.

It would have rendered the diagram unintelligible had I attempted to represent by lines the exact progress of even a single ray through the substance of the glass, in order to exhibit as great a number of angular reflexions and re-reflexions as would occur in its passage through the medium to different points of the interior surfaces of the prism. The

diagram, therefore, is intended merely to shew the *principle*, but not its exact working, which is to be gathered from the present and from other parts of this Essay. I need only remark, therefore, in this place, that the angular reflexions in question are repeated from surface to surface of the three interior sides of the prism, following the direction of the arrows, till, becoming fainter and fainter after each repetition, the last ray is lost in depths of azure. Thus, by how much greater the number of reflexions and re-reflexions suffered by a single ray of light, by so much the more will its illuminating power be reduced: if they be few, the reds and the yellows will preponderate; if many, the blue or azure. For as the prism has three sides, so are those sides, by their lateral shadows, separately represented by a red, a yellow, or a blue, the last ray always participating of the colour belonging to the side of the prism from which it takes its final departure.

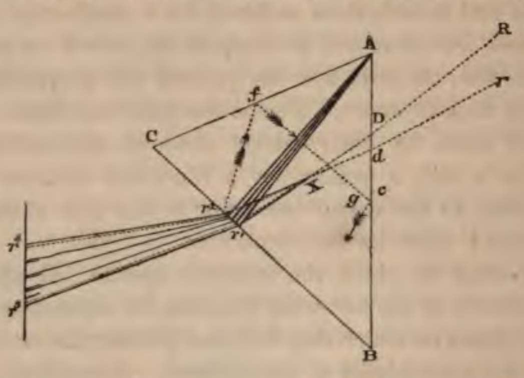
The manner in which the inverted spectra fall upon each other is shewn in the following diagram, by separating the respective planes on which they fall, and placing the latter side by side, for the convenience of comparison. Accordingly, in this example the boundary lines of each coloured space are (though not accurately) marked by black lines, and the dotted lines on the upper spectrum indicate the places at which the edges of the second spectrum fall. The spaces are unequal in width, and some of the edges fall so near to each other, as, by their vicinity, to mark that place more distinctly, and thus to shew an immediate connection between them and the "physical lines" of Fraunhofer, as will be further shewn in the next diagram.



With respect to the three colourless spectra, it is sufficient to say, that when reflexions take place at the *angle-proper*, and therefore emerge from the prism before a ray becomes achromatized by lateral shadows, the result issues in a white spectrum only.

In regard to the "physical lines," a single example of the phenomenon and of its ruling principle will suffice for an explanation.

In the following diagram, A B C represent the section of a triangular prism of glass; R and *r*, two intermediate conjugate solar rays, which, after impact on D and *d*, of the side A B, enter the body of the glass, and crossing each other midway between the two surfaces A B and A C, and emerging from the latter at r^1 and r^2, finally fall upon a sheet of paper at the points r^3 and r^4 respectively. Now it has been shewn by Grimaldi's experiment, that even rays of light, at the points of



their crossings, produce "a remarkable degree of obscurity;" therefore, in this instance, that "obscurity" is exhibited by the ray R from X to r^1, and by the ray *r* from X to r^2, which, falling on the paper r^3 r^4, form the external boundaries of the two colours respectively which should appear at those parts of the paper.

But the external edges of the angles A, B, and C cannot be made absolutely sharp, therefore the interior portions of each blunt edge will be received as a dark shadow upon the interior surface of the side immediately opposite, and thus its image will be transferred to some point between r^3 and r^4, by the action of passing rays. And since also the rays R and *r*, after impact on r^1 and r^2, are thence reflected at the *angle-proper*; therefore, by alternate reflexions and re-reflexions of light and of lateral shadows, and by the partial illumination which the latter receive, the whole remaining portion of the luminous matter is exhausted or dissipated within the substance of the prism. The angular convolutions thus per-

formed by the reflexion of rays cause the dark shadows from the interior edges of the angles A, B, and C to be transferred from opposite sides to corresponding points on the paper r^3 and r^4; and by the concurrence of many of these shadows at contiguous points, the development of the "physical lines" of Fraunhofer's solar spectrum is completed. These lines, too, are rendered darker and broader, by subordinate lateral shadows from the three angles and sides of the prism, and from the points on which the several rays impinge.

From all that has been said, therefore, it would appear that the gradations of colour in nature are chiefly owing to the mutual and co-ordinate effects of *lateral shadows* and *collateral irradiation*, and that the colours of the prismatic spectrum are owing to the oft-repeated action within the glass of the same two principles. It would seem, moreover, by the present experiment, and by that recorded at page 5 of this Part of the Essay, that the medium of glass also operates upon the matter of light in two other ways; namely, 1, by retarding its velocity, and, 2 (consequent thereupon), by lowering its temperature probably. I say probably, as a strong analogy is found to exist between temperature and colour. Thus, if a wedge of steel be heated, and allowed to cool gradually, it will exhibit on its surface all the colours of the prismatic spectrum: the red succeeding to the white is followed by the yellow, the red, and so on, down to the last, namely, the blue, which latter, as far as the nature of the material when cold admits, will become permanent, as may be seen in watch springs, &c.

Analogous effects take place in the atmosphere. Near to the surface of the earth, at sunset, the temperature of the former acting immediately upon the rays of light thence thrown upwards by *collateral irradiation*, produces a red colour in the sky. Higher up, at a point at which the heat is less felt, the collateral light becomes orange, then yellow; and as the rays ascend into the higher regions of the atmosphere, and become less and less influenced by radiant heat from the earth, they pass through the other chromatic changes of the scale, such as the green and blue, and terminate finally in profound azure on reaching the freezing zone.

So likewise in water: when shallow, the solar beams reaching to the bottom, raise its temperature, and a pale green is reflected from its surface; but when the sun's rays are incapable of penetrating to unfathomable ocean depths, where, perhaps bound in gelid chains, "Cimmerian darkness dwells," there only a profound azure is reflected.[1] Night, too, shrouded in deepest azure, reflects no other tint; for, to use the language of Lucretius, What colour can there be in thick darkness, since colour is changed by mere light, appearing different as the rays strike more or less obliquely? And, as in the plumage (especially around the necks) of doves appears to reflect different colours, as the sun's rays strike differently upon it, so in one case it reflects the red of the carbuncle, and in another the mixed green of the emerald with blue. The tail of the peacock, when bathed in a flood of light, changes colour according to the position from which it is viewed; and since all these colours are produced by a mere effect of light, therefore, without that light, colour could not be produced at all.[2]

If solar light be refracted through a lens, or converged to a point by a reflector, the spectrum remains white; but as a much larger quantity of luminous matter is thereby diverted from its natural course, and accumulated on one point, the flood of white light becomes there so intensely vivid, as to produce incandescence or combustion.

With regard to the permanent colours of bodies, the great diversity they exhibit is owing, probably, to the peculiar tint which each body is disposed to exhibit on reaching its frigid state, as in the case of steel.

[1] Humboldt. in using the cyanometer of Deluc or Saussure, states, that during fine weather the sea changed colour from the usual green to deepest indigo-blue, darkest green, or slate-grey, without any perceptible atmospheric change. And he proved that the expression, "the ocean reflects "the sky," is purely poetical, as the sea is often blue when the sky is almost totally covered with light white clouds.—*Vide* Cosmos, p. 47.

[2] "Qualis enim cæcis poterit color esse tenebris,
Lumine qui mutatur in ipso, propterea quod
Rectâ aut obliquâ percussus luce refulget?
Pluma columbarum quo pacto in sole videtur,
Quæ sita cervices circum, collumque coronat:

Among those who have most contributed to the advancement of science, and whose writings are replete with suggestive thoughts, no name is more deservedly respected than that of Count Rumford. In one of his papers, published in the "Transactions of the Royal Society,"[1] will be found some interesting remarks upon coloured shadows; but although it appears to have been his intention to follow up the subject by further communications, I am not aware that he ever carried it into effect. Enough is said, however, in that Paper, to attract attention.

But even at an earlier period the observant eye of Leonardo da Vinci was attracted by the effects of coloured shadows, of which he gives examples in his "Treatise on Painting." He indeed seems to have had a true appreciation of the action of these shadows; but his precepts have been too much neglected. The principle he enunciated is this: that "the "superficies of an opaque body participates of the colour of an "object from which it receives light." The example given is that of a perpendicular column, whose shadow, at the time of sunset, is projected on a wall at a short distance from it; and since that portion of the superficies of the wall upon which the shadow falls is not illuminated by the direct rays of the setting sun, therefore it "receives only the reflexion of the blue "sky; while the rest of the wall, receiving light immediately "from the sun, participates of its red colour."[2]

The truth of this statement may be proved even at midday, when the sun, as it were, equally divides the visible ethereal hemisphere, and when the radiation of light from that

Namque alias fit, uti rubro sit clara pyropo;
Interdum quodam sensu fit, uti videatur
Inter cæruleum virideis miscere smaragdos.
Caudaque pavonis, larga cum luce repleta'st,
Consimili mutat ratione obversa colores;
Qui, quoniam quodam gignuntur luminis ictu,
Scilicet id sine eo fieri non posse putandu'st."

Lucret. lib. ii. ver. 797, &c.

[1] Phil. Trans. Abridg., Vol. xvii. p. 370.

[2] Treatise on Painting, by Leonardo da Vinci, Translation, p. 136. London, 1832.

luminary spreads to too great a distance around him to enable us to perceive the particular colour of which a given shadow participates; for when it falls upon a light ground, such as a chalky road, it then acquires a far more brilliant and transparent purple hue than any which is seen in the sky.

In order to ascertain whether the phenomenon of coloured shadows is dependent upon the principle of *inflexion* or *diffraction* of light, according to the definitions of Grimaldi and Young, I made

Exp. 28. Having fastened a string vertically across the aperture of my reflecting telescope (an instrument of 7 feet focal length and 9 inches diameter), and pointing it towards the clear blue sky, I looked down upon the object speculum, in which I perceived a double image of the string. The image on the right being well defined, was reflected of the natural colour in shadow; but that on the left, being of a dull *indigo* tint, had its edges imperfectly defined. The angular space between the spectra appeared to be about 4-tenths of an inch of arc of a circle whose radius is 9 feet. Every other part of the speculum, however, reflected the natural colour of the sky towards which it was pointed.

I next turned the instrument into the direction of a patch of grey clouds. This change had no other effect upon the double images reflected, excepting that the edges of the image on the left were made out somewhat better than before.

Upon my directing the telescope towards a stone wall shaded by position from direct solar light, and rendered still more obscure by the overhanging foliage of a tree, I perceived, that while the illuminating effect produced upon the speculum was feeble, both images of the string were rendered nearly equal in strength and more alike in local colour; *but the angular space between them now assumed a dull indigo tint.* This colour was strictly confined within the space in question, all beyond it exhibiting only the natural appearances of external objects reflected in the mirror.

Similar effects were witnessed on looking at the same objects by the usual side view in the instrument; but on the latter

occasion, as the eye was within the focus of the object speculum, the relative position of the two images was changed; the fainter one now appearing on the right, into whatever direction the instrument might be pointed; but when turned towards a very bright object, such as a strongly-illuminated cloud, the central or resultant effect was so vivid, whether by a front or a side view, that only one strong, tremulous image of the string became visible.

The result of this experiment shews that the *indigo* tint which occupied the space indicated by the binary reflexion of the string, could only be produced by the string's *lateral shadows,* also binary, the overlapping of which between the images forming a section common to both laterals, gave rise to the coloured space or shadow of which we are speaking. But as no similar duplication could take effect exteriorly to the double images of the string where they were only single, no such colour appeared elsewhere.

Now if the eye itself were capable of supplying, as an *accidental colour,* this *indigo* tint, there must be, in the constitution of the organ, some property by which such purely local effect was caused. What then is its constitution?

Sir Everard Home states, as one of the results of his investigation of the human eye, that in health the colour of the retina is blueish.[1] If, therefore, light on its passage out of the eye be affected by the tint of which this membrane is possessed, the effect must necessarily be general, not local, as in the present case.

On the other hand, Scarpa declares that the retina is an opaque membrane, on which account, he says, it reflects the black colour seen through the pupil.[2] Haller, however, having gone farther than this, not only asserted that the membrane is opaque, but also stated that its colour is ashy-yellow. (*ex flavo subcinerium*).[3]

Then, with respect to the choroidea, Petit says it is brown in childhood, a little less so at twenty, gridelin or grey violet at

[1] Phil. Trans. Abridg., Vol. xviii. p. 457.

[2] Trattato delle Malattie degli Occhi, tom. ii. p. 221. Pavia, 1806.

[3] Elementa Physiologiæ, Tom. v. p. 285.

thirty; and, as life advances, that it becomes lighter and lighter till, at the age of ninety, it is nearly white.[1] No inference more favourable to this exceptional case, therefore, can drawn from the latter facts.

Furthermore, the vitreous humour retains through life a somewhat yellowish colour;[2] but the crystalline, on the contrary, is wholly colourless at twenty years of age, yellowish at thirty, straw-coloured at forty or forty-five, and will have acquired, at seventy or eighty, the appearance and consistency of amber.[3] Finally, it has been shewn in Part I. of this Essay, that the cornea is a purely colourless membrane.

It may be assumed, then, that by no effort of the WILL exercised upon the organ, being in health, and by no combination of physical circumstances affecting the function of vision, could the eye, by an independent action, originate *subjectively* the local colour in question as seen on the speculum. The entire effect, therefore, must be attributed to the duplication of subordinate binary shadows at the place indicated. Indeed, if we compare the chromatic result of the present experiment with that of Grimaldi's two luminous cones, and with those of Newton's human hair and filament of silk, we shall be satisfied that the development of colour is not an organic effect, but the immediate result of a physical action produced by *lateral shadows* upon the *light of collateral irradiation*.[4] And although the eye, considered as an optical instrument, is far more perfect than any one designed to aid

[1] Mémoires de l'Academie Royal des Sciences, pour Ann. 1726, p. 209.

[2] Ejusdem. [3] Idem, p. 113.

[4] The following experiment will exhibit the true principle upon which harmony and dissonance of colour depend; which principle, if carried to its proper extent, will open a wide field for the study of the flower painter, and perhaps lead to important results in the science of chromatics:—

Place six slips of blue, green, and purple-coloured paper, or lambs'-wool, promiscuously on the right side of a stereoscope camera, and the same number of red, orange, and yellow, also promiscuously, on the left side of the same camera. Then, on looking through the tubes, the respective colours of the two groups will appear to be translated from a side to a central view, and to be there as perfectly mixed together as if that

vision executed by the hand of man, it is, like the latter kind, liable to be affected anomalously by these disturbing properties of light; so much so, indeed, that unless the WILL be exerted for the purpose of accomplishing distinct vision by exercising a power of *selection* in regard to the individual object upon which, at the moment, we may wish to employ the faculty, the effect of double vision with two eyes, and even with one, will be the immediate consequence of the above-mentioned action of light upon the physical organ. That such a result has proved very perplexing to writers on optics is evident from the fact, that De la Hire, quoting the case of a near-sighted person to whom a single hair-line drawn upon the white face of a sun-dial appeared double, makes this

operation had been performed by the hand instead of the eye. This is, of course, an optical deception. But the law of *impenetrability* of matter, in coming into force, here shews how physically impossible it is for two *opaque* bodies to occupy the same visible area at the same time; for when the apparent transfer of colours takes place by the concurrent action of both the eyes, if any two of the former fall into the same line of sight, one of them shall be obliterated, and the other remain: if a *red* vanish, the group will appear too *cold;* if a *blue*, too *warm*. If they be in too close proximity to certain other colours, they shall wholly, or partially, disappear from sight. And if two colours diametrically opposed, as a red and a green, cross the central line of vision, so that by spreading, parts of both shall be seen together, they will slowly and progressively recede from each other, and thus require a continued exertion of the MIND, acting upon the muscular apparatus of the organ, to bring their images back, and retain them steadily in view, even for a single moment. The operation will be nearly as fatiguing to the eye as when the two *nearest halves* of a geometrical figure, drawn in white lines upon a black ground, are made to join symmetrically by the crossing in the stereoscope of the optic axes, in the manner described in Part II. of this Essay.

But another effect likewise takes place; for as, in point of fact, the warm and the cold colours remain stationary during the above operation, and rest upon the same plane, the eye itself will appear to change their relative position within the optic angles, so as sometimes to bring the warm colour before the cold one, and sometimes the cold one before the warm, according as the right or the left eye *takes the leading part*, it being a condition necessary to distinct vision, that one eye alone shall exercise the dominant power.—See Part II. of this Essay. And as the eyes, in this respect, are perpetually changing the lead in vision, as when directed to a near or a distant object, and as each eye sees that object

remark : he says, " This is one of the most difficult phenomena " to account for, and can only be explained on the assumption " that the crystalline lens of the individual was formed according to the figure of Nicomede's conchoide."[1]

Again, Dr. Briggs considers the operation of single and double vision as depending upon a perfect or an imperfect tension of corresponding fibres of the optic nerves distributed to the organ from the brain, so that, when the corresponding fibres receive isochronous vibrations, they stir up a single sensation in the mind; but when an image falls on parts of the retinæ the tension of whose fibres does not correspond, the discordant impressions thereby resulting stir up two sensations in the mind.[2] Indeed, the doctor is so well satisfied with the harmony of his theory, that he reduces it to the form of an equation; thus, " 1. Why is vision not double since the " organ is so? Because the fibræ concordes are like unisons " in the lute, and the rays strike both at the same time. " 2. Why, upon pressing down one eye, does an object appear " double? Because the rays then fall upon discordant fibres in " this and the eye not pressed, so that two sensations are " excited in the mind."[3]

Kepler thought that the union of the nerves anywhere between the two retinæ and the brain is repugnant to the double appearance of an object, because, if the nerves are thus united, double vision would be impossible.[4]

Baumer imagined that the cause of double vision with the

under a different angle, hence the dazzling effect produced upon the sight by certain combinations of colours, especially when arranged into zig-zag, or spotted, patterns on the paper of walls, or on carpets. Hence also the phenomenon of the appearance of loose colours in the "lambs'-wool puzzle," and of relief in stereoscopic views. In the former cases the phenomenon depends upon the duration of an impression upon the retina: in the latter it is owing to the physical translation of the planes on which the objects stand, as well as to adverse polarities, the unequal power exercised by the two eyes, and the different optic angles under which their mutual operations are performed.—See ante page 20.

[1] Traite des differens Accidens de la Vue, p. 156; idem, p. 243.

[2] Nova Visionis Theoria, p. 25.

[3] Phil. Trans. Abridg., Vol. ii. p. 543.

[4] Diop. prop. 62.

two eyes is that the crystalline of one eye must be slightly out of centre with the optic axis.[1]

Cheselden attributes the performance of single vision to the education of the organ by means of the sense of touch, and by the exercise of the former upon objects which, by the aid of the latter, the mind knows to be single. In support of this hypothesis, he cites the case of a patient who, having received a severe contusion of the head, and the injury causing a distortion of one of the eyeballs, he saw every object double; but, by accustoming his mind to perceive as single familiar objects which appeared to be double, he recovered the faculty of single vision, although the distortion of the eyeball remained.[2]

Both Berkeley and Locke seem to imagine that our perception of external objects, in regard to single vision, depends upon the education and a proper exercise of the organ, but they are at issue as to the aid which the faculty of vision receives from the sense of touch.[3]

Dr. Smith, as well as Dr. Jurin, likewise conceives that single vision is the result of habit, alleging, in support of the notion, that any unusual mode of exercising an organ of sense, such, for example, as when a single object is felt by two fingers of the same hand crossed, this will cause the judgment to be deceived by a double sensation; and, he remarks, "Had "we a hundred eyes, in the ordinary and constant use of them, "an object would appear single ordinarily, and centuple in "extraordinary cases."[4]

Raghellini instances the case of a patient to whom, after the operation of "double pupil" had been performed, single objects appeared double.[5] Letin refers to another case, in which the patient saw triple.[6] And, finally, Dr. Porterfield, as well

[1] Justi, Baldiger, N. Mag. blünde xi., p. 446.

[2] Cheselden's Anatomy, p. 324, second edition.

[3] See Berkeley's Essay on Vision, p. 172, a work kindly lent to me by Dr. Lee; Locke on the Understanding, book i. chap. 9. sect. 8.

[4] Smith's Optics, Vol. i. p. 49.

[5] Lettera al S. Cocchi sopra l'offessa della vista in una Donna. Veneta, 1784.

[6] Lib. ii., Obs. 20.

as Huygens, Baumer, and Young, conceives that the cause of double vision is to be traced to a slight displacement of the crystalline from its central position with respect to the axis of the eye.

But authorities upon the subject might be quoted *ad libitum*, each differing slightly on minor points, but agreeing in the main; yet, strange as it may seem, all appearing to have overlooked the two real causes of double and single vision, namely, the one depending upon the operation of a principle of light, by which double and multiple shadows of single objects are produced; the other upon the exercise of the faculty of VOLITION, in regard to *choice* or *selection* of objects, as explained in Part II. of this Essay.

In aid of the commanding position which the MIND occupies in the performance of single vision, the eye is furnished with an apparatus of great efficiency and simplicity, upon which the WILL (exercising discretionary power, and acting upon the appropriate muscles through the agency of nerves supplied from the brain) enforces its commands by putting it in motion for the accomplishment of the intended effect. Thus educated, single vision is performed without an appreciable effort, and, consequently, without exhaustion of nervous energy. Without this education, the mental faculty by means of which a *voluntary selection* is made would be useless; so that here, again, double vision would be the rule, single vision the exception.[1] But the education here spoken of is acquired intuitively at a very early period of our existence (about three weeks after birth), and it is never afterwards lost, except from an overruling abnormal defect; and whether internal injury or external force cause the efficiency of the organ to become impaired, the result will be the same as when, according to Lucretius and Briggs, a finger presses against the eyeball so as to interfere with the muscles of voluntary motion. In this case vision becomes distorted and confused—men, animals, houses, trees, every object appearing double, will fully realize to the MIND of the individual the description of the ancient poet:

[1] See Part I. of this Essay; also ante p. 58.

"At si forte oculo manus uni subdita, subter
Pressit eum; quodam sensu fit, uti videantur
Omnia, quæ tuimur, fieri tum binà tuendo;
Bina lucernarum florentia lumina flammis;
Binaque per totas ædeis geminare supellex:
Et duplices hominum facies, et corpora bina."
Lucret. lib. iv. ver. 449, &c.

Such, then, are some of the properties of light which, at the commencement of this Part of the Essay, I proposed to bring under consideration; and although the subject is far from being exhausted, I apprehend that sufficient evidence has been adduced to establish the assertion of Count Rumford, that "*the eye is not always to be trusted.*[1]" I have endeavoured to shew why it "is not always to be trusted," and have pointed out a few of the exceptional cases, or anomalous conditions of the organ, under which we are liable to be deceived by appearances, and to make false judgments in vision. For the MIND or SOUL, the only intelligent portion of our *being*, although partaking of a divine nature, and itself "immortal and invisible," is so restricted in the exercise of its faculties by its association with the flesh, that it neither hears, nor feels, nor sees, without the co-operation of the natural element. It knows absolutely nothing by itself either of the mortal coil in which it is encased, or of the external circumstances by which it is surrounded. It derives its information upon these and upon other matters relating to its happiness and well-being solely through impressions received from its handmaidens, the organs of sense. From their combined or individual report alone, after undergoing the scrutiny of a sound judgment, it forms its notions of the external world, and of its own internal perceptions, feelings, and faculties. By their aid it is enabled to embrace within the range of its contemplation faint ideas of the power and wisdom of that GREAT BEING by whom all things were created and fashioned, according to the determination of HIS WILL, upon a scale of grandeur, solemnity, and symmetrical beauty, far exceeding the bounds of imagination to conceive, and displayed to us in worlds and

[1] Loco citato.

planetary systems harmonious, unnumbered, and fitly organized in all their several parts, and maintained in stability and efficiency by the same laws which HE originally impressed upon matter, and which still govern and control not only our own system, but

> "World beyond world, in infinite extent,
> Profusely scattered o'er the blue expanse."
> *Thomson's* Seasons—Autumn.

—Worlds and systems occupying their appointed places in sidereal space, many of which are at such immeasurable distances from us that the imagination is bewildered at the thought. Systems, indeed, of whose existence, even, we should have known nothing had not their SHADOWS-IN-LIGHT[1] been projected sufficiently near to our orbit to be caught up, and, as it were, secured to us by telescopes of such enormous optical powers as that of Lord Rosse, and of the United-States' Observatory, ere those *luminous shadows* were melted and absorbed into the unfathomable azure abyss of illimitable ether. In short, had the MIND been deprived of the right co-operation of the organs of sense, it would have been incapable of exercising the faculty even of contemplation: it would be ignorant of its own existence: senseless, and without emotion, it would be a solitary blank, the only bleak and sterile spot in nature. Nor healthful breeze, nor evening dew, nor sunny morn, nor song of bird, nor voice of soothing friend, nor cheering hearth, could fill the void, or refresh the spirit, or nerve the vigorous arm, or sustain the throbbing heart, or still the strife of conflicting elements within, or the jar of opposing principles without, until the hour of the body's dissolution should have come, and life's feverish dream were ended.

[1] *Ante* p. 14.